THE IMPACT OF THE AUTOMATIC FUEL ADJUSTMENT CLAUSE ON PRODUCTION EFFICIENCY FOR ELECTRIC UTILITIES

BY

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This dissertation is dedicated to my parents, whose love and support are a constant source of inspiration.

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This study examines the impact of the automatic fuel adjustment clause on industry performance. The opening chapter contains an introduction to this regulatory tool. A brief history of the implementation of the automatic fuel adjustment clause, as well as a discussion of its costs and benefits to society, is contained therein. The introduction is followed by a review of both theoretical and empirical evidence on the relationship between the presence of an automatic fuel clause and firm performance.

A simple theoretical analysis of the impact of the automatic fuel adjustment clause on firm behavior is presented in chapter three. Using a three factor model, the firm's profit maximizing input combinations are derived under several scenarios. First, the impact of the automatic

fuel adjustment clause on input usage is examined when the adjustment clause is the only form of regulation. Next, input usage is analyzed in the presence of an automatic fuel adjustment clause and rate of return regulation. Finally the assumption of perfectly variable inputs is dropped and the impact of the automatic fuel adjustment clause on input usage is examined in the presence of a fixed capital input. The basic model is extended to examine the relationship between factor utilization and the various components of the automatic adjustment clause. The question of the impact of the automatic fuel adjustment clause on technical efficiency is briefly addressed.

Chapter four contains an empirical analysis of the impact of the automatic fuel adjustment clause on cost efficiency. Cost frontiers are estimated for firms subject to automatic fuel adjustment clauses as well as for firms not subject to this form of regulation. Efficiency measures are computed and compared based on the positions of the frontiers as well as the positions of the firms relative to those frontiers. Both long run and short run efficiency estimates are presented.

The concluding chapter contains a brief outline of the study's contributions. Suggested areas for further research are also discussed.

CHAPTER ONE

INTRODUCTION

The Methodology of the Fuel Adjustment Clause

The fuel adjustment clause was introduced as a method of rate making for electric utilities in 1917 [1]. It became a widely recognized and generally accepted regulatory tool by the middle 1920's. By the 1970's its popularity had soared. As of 1978, a fuel adjustment clause was utilized in 43 states and the District of Columbia. Only Idaho, Montana, Oregon, Utah, Washington and West Virginia failed to permit rate changes according to a fuel adjustment clause. Nebraska does not regulate electric utilities.

Although the specific formulation of the fuel adjustment clause varies across states as well as across companies within a single state, its formulation can be generalized as follows:

$$FAC_t = (FE_t/Q_t - FE_o/Q_o - ADJ) \times TF \qquad 1.1$$

and

$$P_t = P_o + \phi \, FAC_{t-1} \qquad 1.2$$

where

FAC_t = fuel adjustment factor for period t.

FE_t = fuel expense for period t.

Q_t = quantity of output sold in period t.

FE_o = fuel expense for the base period.

Q_o = quantity of output sold in the base period.

ADJ = adjustment factor to correct for overcollection or undercollection of expenses.

TF = tax adjustment factor.

P_o = price of electricity in the base period.

P_t = price of electricity in period t.

ϕ = percentage of cost increases which are permitted to be passed on.

ℓ = length of the lag between the utility's incurrence of the fuel expense and recovery from customers [2].

The fuel adjustment clauses differ in several aspects. First, the definition and computation of the fuel expense for period t varies from state to state and from company to company within some states. It is generally defined to include fossil fuel expense as well as some other types of expenses. As of 1978, most states permitted nuclear fuel expenses to be included in the fuel expense under the fuel adjustment clause. Only Alabama, Connecticut, Illinois, Mississippi, Missouri, New Hampshire and Wyoming expressly prohibited the inclusion of nuclear fuel costs. Other items which are commonly permitted to be included are purchased power costs and fuel handling and transportation costs. The treatment of the purchased power costs, however, is not uniform even among states permitting its inclusion in

the fuel expense. Several states permit the full cost of purchased power to be included while others allow only the fuel component. Table I-B of the publication entitled Stats Commission Regulation and Monitoring of the Fuel Adjustment Clause, Purchased Gas Adjustment Clause, and Electric and Gas Utility Fuel Procurement Practices by the National Association of Regulatory Utility Commissioners contains a summary of the items permitted to be included in the fuel expense by state [2].

States also differ on the time frame for the calculation of the fuel expense. Some states base the fuel adjustment clause on actual expenses incurred while others use estimated expenses. If actual expenses are used then some lag is clearly required in the pass-through of costs. If, on the other hand, estimated expenses are used, a lag is not necessary. In this case, however, an adjustment factor is required to correct for overcollection or undercollection of fuel expenses due to forecasting errors.

Relatively few fuel adjustment clauses contain a tax provision. As of 1978, only Alabama, Arkansas, Hawaii, Illinois, Iowa, New Mexico, Pennsylvania and Texas had any provision for the pass-through of taxes via the fuel adjustment clause. Furthermore, with the exception of New Mexico, the types of taxes covered were severely restricted. (The Public Service Commission of New Mexico has an indexing system which allows for the pass-through of changes in all costs.) The tax most commonly incorporated

into the fuel adjustment clause is the state gross receipts tax. The standard form of the tax adjustment factor, when utilized, is simply 1/(1-tax rate).

The various regulatory authorities also differ with respect to the deflation of the fuel expense. The vast majority of states deflate the fuel expense in all periods, including the base period, by the quantity of electricity sold thus arriving at a cents per kilowatt hour fuel cost increase for billing purposes. In this way, line losses are implicitly built into the fuel adjustment clause and the associated cost of fuel is passed on to the consumer.

Connecticut, Oklahoma and Florida do not use sales to deflate fuel expense. In these states, the fuel expense is deflated by millions of BTU's consumed of fuel. The change in fuel cost per million BTU's is then multiplied by the heat rate to arrive at the price increase per kilowatt hour. Generally, the heat rate is not recalculated each period, and it is argued that such an arrangement improves the utility's incentive to minimize heat rate for a given load [3]. It can also, however, result in over-collection or undercollection of fuel cost increases due to changes in the generation mix as more or less efficient units are utilized.

Another factor which varies across fuel adjustment clauses is the length of the pass-through lag. The pass-through lag is simply the length of time between the change in the utility's fuel expense and the pass-through of the

increased or decreased cost to the customers. As of 1978, seven states had no pass-through lag so that cost changes were immediately passed on. With the exception of two states, the pass-through lags were less than or equal to three months. The exceptions were Nevada and Vermont with lags as long as nine months. The value of the lags, by company, can be obtained by consulting the National Electric Rate Book [4]

There are several other inter-state differences in fuel adjustment clauses as well. Some states have threshold provisions which prevent fuel cost changes to be passed on to consumers if those changes fall short of some specified amount. The proportion of fuel cost changes which can be passed on to consumers also varies across states although, as of 1978, the most common value for ϕ was one [2]. The inventory method for fuel accounting, which determines the allocation of fuel expenses among different billing periods, also differs from one fuel adjustment clause to another. The methodology for determination of fuel costs when, as in the case of coal, the utility may own the mine, also lacks uniformity across regulatory bodies [5]. For all of these reasons, fuel adjustment clauses can only be specifically compared or contrasted after consulting the fuel adjustment clauses of interest.

Perhaps the most important differences in fuel adjustment clauses, across regulatory agencies, have yet to be discussed. These are the differences in the monitoring and

regulation of the fuel adjustment clause. As of 1978, thirty one states had what can strictly be considered an automatic fuel adjustment clause for electric utilities. In those states, fuel cost increases could be passed on to consumers according to the fuel adjustment clause with no formal hearing required. In the remaining states with fuel adjustment clauses, some sort of formal review or hearing was required before a rate change could be implemented via the fuel adjustment clause.

A formal fuel adjustment review requires advance public notice of the hearing, testimony from affected parties and a formal decision from the regulatory board. The formal fuel adjustment reviews are similar in procedure to the ordinary periodic rate reviews held under rate of return regulation. The distinguishing characteristic is that only issues pertaining to the utility's cost of fuel and the proper implementation of the fuel adjustment clause based on those cost changes can be discussed.

While those utilities subject to automatic fuel adjustment clauses are exempt from formal reviews before rate changes can be implemented, all automatic fuel adjustment clauses and their associated rate changes are periodically reviewed to some extent. Most utilities are required to file fuel adjustment clause calculations routinely, most commonly on a monthly basis, and these calculations are regularly checked. In addition to these minimal requirements, electric utilities in eleven states are subject to

regular periodic spot checks of their electric generating plants at annual or more frequent intervals [2]. Electric utilities in ten other states are subject to spot checks on an "as needed" basis.

In addition to the regular monitoring of the fuel adjustment clause, the National Energy Act requires periodic review of the fuel adjustment clause itself and the revenues collected thereunder. At this time, the question of the necessity of a fuel adjustment clause is addressed. Also, the impact of the fuel adjustment clause on the utility's procurement and utilization of fuel is analyzed. Finally, the overall performance of the utilities subject to this form of regulation is evaluated, and the reasonableness of rate changes is verified.

The Purpose and Benefits of the Fuel Adjustment Clause

According to the NARUC, the fuel adjustment clause serves three basic functions [2]. First of all, it protects the utility from earnings erosion during periods of fuel price inflation. In the presence of a fuel adjustment clause, the higher fuel cost can be passed on, in full or in part, to the utility's customers. This is especially important with respect to fuel costs as fuel is the largest cost element for a majority of utilities. Second, the fuel adjustment clause provides the utility's customers with rate reductions when fuel prices fall. This is because fuel cost changes in either direction are passed through

to customers via these clauses. In both cases, prices may tend to better track short run marginal costs thus promoting allocative efficiency. In addition, a third function of the fuel adjustment clause is the reduction of regulatory costs. Because the utility does not suffer severe earnings erosion in times of fuel cost increases or enjoy excessive profits in periods of fuel cost reductions, fewer general rate reviews are required thus saving the utility and taxpayers the expense of such a proceeding.

Blair and Kaserman break down the regulatory savings from the reduction in the frequency of rate reviews into explicit and implicit savings [6]. The authors report that the explicit or monetary cost for a typical rate case for a moderately large electric utility is between three hundred and five hundred thousand dollars. In addition to the explicit costs of a rate review, there are implicit costs. With fewer rate reviews, regulators as well as company personnel should be able to focus more attention on other aspects of the operation of the utility. This should, of course, improve overall operation efficiency. Unfortunately there are some offsetting costs involved. As previously discussed, there are monitoring and regulation costs associated with fuel adjustment clauses--even automatic fuel adjustment clauses. However, it appears reasonable to argue that the fuel adjustment clause results in a net reduction in regulatory costs until an empirical analysis can be conducted.

Scott addresses another potential benefit associated with the fuel adjustment clause [7]. He demonstrates, theoretically and empirically, that a fuel adjustment clause reduces profit variance for the utility. The reduction in profit variance represents a risk reduction to the utility's investors. And a risk reduction should reduce the cost of capital to the utility. The New Mexico Public Service Commission estimated that the fuel adjustment mechanism resulted in a total capital cost savings of between nine million dollars and sixteen million dollars for the period 1973 through 1977 and forecasted capital cost savings through 1982 to be as high as 100 million dollars [3, p. 52].

The History of the Fuel Adjustment Clause

A review of the history of the fuel adjustment clause demonstrates that its implementation appears to have been consistent with the previously discussed objectives. The fuel adjustment clause for electric utilities was first introduced during World War I. This was a period of rapidly increasing coal costs due to shortages of labor in mining and the increased demand for rail transportation [8]. Since coal represented about 50% of the operating costs for a typical electric utility and the cost increases were clearly beyond the control of the utilities, protection from earnings erosion was undoubtedly warranted.

In the postwar period of the 1920's, coal prices stabilized and the fuel adjustment clauses were, for the most part, eliminated. Schmidt argues that the fuel adjustment clauses should have been maintained through this decade [3, p. 965]. Being a period of increased demand for electricity, the utilities were experiencing a reduction in per unit production costs due to economies of scale. If the fuel adjustment clauses had been maintained, part of the cost reductions would have been passed on to consumers. It is not clear, however, that the perpetuation of an unnecessary form of regulation for other than the originally intended purposes would have been justified.

The first request for a tax adjustment clause was made in the 1930's. It was in response to the many new and increased taxes of the New Deal era [1, p. 31]. The regulatory authorities ruled that the cost increases were not sufficient to warrant protection for the utilities. No tax adjustment clauses were granted in this period.

With the outbreak of World War II, the nation was again faced with the problem of spiralling inflation. The cost increases were viewed to be generally beyond the control of the electric utilities and they were again granted relief from earnings erosion in the form of fuel adjustment clauses. It was also during this period that the proposal to adopt a uniform adjustment clause first surfaced. The proposal is still alive today but has yet to be approved.

The first adjustment clause to cover tax increases was implemented in the postwar period of the 1940's. The tax relief measure for utilities was popular with regulators who were concerned with uncertainty concerning the recovery of new taxes would be reflected in the capital market [9]. The tax adjustment clause was designed to reduce investor risk thus preserving the financial integrity of the utility.

In the early 1950's the Korean War again caused fuel prices to increase and regulators responded by increasing the use of fuel adjustment clauses [1, p. 966]. It was during this period that fuel adjustment clauses were first extended to apply to residential rates. By the late 1950's, the number of fuel adjustment clauses in effect declined dramatically. Increases in generating efficiency more than offset the average ten percent fuel price increase during this period, rendering the fuel adjustment clauses unnecessary in the eyes of the regulators [3, p. 34].

The 1960's were characterized by a further decline in the use of fuel adjustment clauses. The market for fuel had stabilized. Also, the proportion of operating expenses attributable to fuel costs had begun to decline [10]. Both developments further diminished the need for fuel adjustment clauses and the regulatory authorities responded accordingly.

The international situation of the 1970's again introduced chaos into the fuel market. This time it was the price of oil which was most dramatically affected. Regulators again afforded the utilities protection from profit

erosion through widespread utilization of fuel adjustment clauses. The application of fuel adjustment clauses to residential rates was popularized in this period, particularly in the Northeast where utilities were especially dependent on oil. As the price of oil continued to increase, the prices of other fuels also began to increase and implementation of the fuel adjustment clause increased in other regions of the country. By the middle 1970's the application of the fuel adjustment clause was almost universal. With the increased popularity of this regulatory tool, concern over its possible adverse effect on the operation of electric utilities was intensified.

Objections to the Fuel Adjustment Clause

The early application of the fuel adjustment clause was limited to non-residential consumers. Thus it is not surprising that the first objection voiced concerning this regulatory tool focused on its impact on the industrial sector [1, p. 968]. It was argued that an unexpected electric rate change would throw the consuming firm's cost-price relationship off balance. Several fuel adjustment clause proposals were defeated on these grounds in the 1920's [1, p. 969]. Since that time, the validity of the argument has been questioned. It has been suggested that a change in the pricing policy for industrial users could prevent excessive hardship. For whatever reason, this objection has received little attention in recent years.

Trigg discusses several closely intertwined legal objections to the fuel adjustment clause which have received considerable attention over the years [1, pp. 970-972]. Perhaps the most popular argument is that a fuel adjustment clause prevents subsequent supervision of the utility's rate structure. This objection is closely related to the charge that the fuel adjustment clause permits electric rates to be increased above what had previously been determined to be reasonable, without full consideration of all relevant factors. In fact, a fuel adjustment clause may permit a rate of return in excess of what has been deemed fair. It is even possible that rates would be allowed to rise when production costs were actually falling. This would be the case if fuel cost increases were more than offset by savings due to a decrease in other factor prices or an improvement in generating efficiency. The third legal objection concerns the procedure necessary to remedy the above undesirable situations. Rates can be reduced to reasonable levels only by revoking or suspending the fuel adjustment clause. The legal problem stems from the fact that the remedial procedure shifts the burden of proof of reasonableness or unreasonableness of the rate structure from the utility to the regulatory authority. Legal arguments such as these were recently successfully employed in Missouri where the Supreme Court of Missouri found the fuel adjustment clause to be illegal.

Trigg discusses another somewhat related but more distinct legal issue. It has been argued that the fuel adjustment clause violates a legal principle that public utility rates should be published and definite. Both lawyers and economists have expressed concern that the utility's customers would be unable to understand the fuel adjustment clause and the electric rates charged thereunder. It is suspected that the uncertainty which may be introduced via the fuel adjustment clause may impose a very real and significant cost on consumers in terms of their overall welfare.

A relatively recent objection to the fuel adjustment clause centers on its impact on the distribution of real income. In many cases, the fuel adjustment clause has not been uniformly applied to all customer classes. In its early years, for example, residential customers were generally exempt. Such discriminatory application presumably caused an income redistribution from the industrial sector to the household sector. The industrial sector was faced with a higher rate than would be charged in the absence of the fuel adjustment clause. And, at the same time, residential customers enjoyed lower rates due to less frequent rate reviews.

Even with uniform application of the fuel adjustment clause, there may be a redistribution of income in the presence of peak load pricing [3]. If plants characterized by higher fuel costs are brought on line during peak hours,

than off-peak users will, in effect, wind up subsidizing peak users. This is because the fuel adjustment clause fails to allocate a higher proportion of fuel cost increase to peak rates.

The objection to the fuel adjustment clause which has received the most attention by economists, however, is that the fuel adjustment clause reduces the utility's operating efficiency. It has been argued that the fuel adjustment clause adversely affects the utility's incentive structure. Because some costs can be passed on to consumers, it has been hypothesized that the utility will have a diminished incentive to minimize the full costs of operation. In fact, cost minimization may be inconsistent with profit maximization.

The Content of This Paper

This study will be concerned with the final objection to the fuel adjustment clause discussed above. The impact of the fuel adjustment clause on several aspects of the utility's efficiency will be theoretically analyzed. Following this an empirical analysis will be conducted. The purpose is to determine whether the fuel adjustment clause does, in fact, impose a cost on society in the form of reduced efficiency and, if so, to determine the magnitude of this cost. This information should be of importance to regulators in weighing the costs and benefits of this regulatory tool.

Chapter Two contains a review of the literature concerning the impact of the fuel adjustment clause on efficiency. This chapter reviews both theoretical models and empirical analyses. Chapter Three presents a theoretical examination of the impact of the fuel adjustment clause on firm behavior, emphasizing the effect on the firm's combination of productive resources. The theoretical study is repeated for several different scenarios. In Chapter Four, an attempt is made to determine whether firms subject to a fuel adjustment clause are any more inefficient than other firms, and whether any inefficiency is actually caused by the fuel adjustment clause. Finally, the study's conclusions are presented in Chapter Five.

CHAPTER TWO

REVIEW OF THE LITERATURE

Theoretical Models

Atkinson and Halvorsen

One of the first theoretical models to examine the impact of the automatic fuel adjustment clause on the firm's combination of inputs was developed by Atkinson and Halvorsen [11]. The authors employ a three factor model with perfectly variable inputs. In period zero, the firm is subject to a rate of return constraint identical to that introduced by Averch and Johnson [12]. In periods beyond the base period, the firm is constrained by an automatic fuel adjustment clause.

The objective of the firm is apparently assumed to be the maximization of profit in each period. For whatever reason, each period is examined separately and the impact of the fuel adjustment clause on the base period's input combination is completely ignored. As will be demonstrated in Chapter Three, if the firm is attempting to maximize a discounted stream of profit, then the fuel adjustment clause will affect the base period's input choices even though the constraint is not binding in that period.

For period t, the firm's objective is to maximize

$$\pi = R(K_t, L_t, F_t) - rK_t - wL_t - \bar{g}P_t \qquad 2.1$$

where

R is total revenue for period t
K is the quantity of capital employed in period t
L is the quantity of labor employed in period t
F is the quantity of fuel employed in period t
r is the per unit price of capital
w is the wage rate
$\bar{g}$ is the per unit price of fuel.

The fuel adjustment clause is imposed on the firm by requiring that

$$R(K_t, L_t, F_t) - w_0L_0 - \bar{g}_0F_0 - s_0K_0 - (\bar{g}_tF_t - \bar{g}_0F_0) \leq 0. \qquad 2.2$$

where s_0 is the regulated rate of return on capital. Again subscripts denote time periods and the most recent rate review is assumed to have occurred in period zero. The authors proceed to form a Lagrangian function, differentiate, and examine the Kuhn-Tucker conditions. Comparing the marginal revenue product ratios for the various factor pairs, it is then demonstrated that fuel will be overutilized relative to both labor and capital in period t.

On the other hand, labor and capital will be properly combined.

The authors' treatment of the automatic fuel adjustment clause varies significantly from this paper. As explained in the previous chapter, the NARUC contends that the fuel adjustment clause is essentially a form of price regulation. Atkinson and Halvorsen instead view the fuel adjustment clause as a revenue constraint. For purposes of comparison, the period t constraint in their model can be expressed as

$$P_tQ_t - P_0Q_0 - (g_tF_t - g_0F_0) \leq 0 \qquad 2.3$$

or $$P_tQ_t - g_tF_t \leq P_0Q_0 - g_0F_0 \qquad 2.4$$

where

P is price per unit of output

Q is quantity produced and sold.

The period zero regulatory constraint insures the following equality which was employed in deriving equation 2.4.

$$P_0Q_0 = w_0L_0 + g_0F_0 + sK_0 \qquad 2.5$$

On the other hand, the period t constraint as viewed by the NARUC could be expressed as

$$P_t - P_0 - (g_tF_t/Q_t - g_0F_0/Q_0) \leq 0 \qquad 2.6$$

or $$P_t - g_tF_t/Q_t \leq P_0 - g_0F_0/Q_0. \qquad 2.7$$

Multiplying both sides of equation 2.7 by Q_0 and by Q_t yields

$$Q_0/Q_t \; (P_tQ_t - f_tF_t) \leq P_0Q_0 - f_0F_0. \tag{2.8}$$

It is now apparent that the constraint expressed in equation 2.4 is equivalent to that of equation 2.7 only if Q_0 is equal to Q_t. This would require that demand, by period t, had grown just sufficiently to offset the reduction in quantity sold which would otherwise be experienced because of the price increase.

It turns out that the direction of the input distortion in period t is the same whether the fuel adjustment clause takes the form of a price constraint or of a revenue constraint. That is, fuel will be overutilized relative to both labor and capital. The treatment of the fuel adjustment clause as a revenue constraint does more than just simplify the mathematics, however. It has important implications in that the indeterminacy encountered in Chapter Three concerning the impact of the automatic fuel adjustment clause on the utility's output is eliminated. Although the authors do not address the question of the impact on output, it can be easily demonstrated that the firm subject to an automatic fuel adjustment clause formulated as a revenue constraint will produce less output than an unregulated firm in periods beyond the base period. The

Kuhn-Tucker conditions for period t, from their paper, can be rewritten as follows.

$$(1 - \lambda)\ \partial P_t Q_t / \partial K_t - r_t \leq 0 \leq K \qquad 2.9$$

$$(1 - \lambda)\ \partial P_t Q_t / \partial L_t - w_t \leq 0 \leq L \qquad 2.10$$

$$(1 - \lambda)\ \partial P_t Q_t / \partial F_t - (1 - \lambda) g_t \leq 0 \leq F \qquad 2.11$$

where all variables are as previously defined. Since the authors demonstrate that λ is positive and less than one, it is clear that for an interior solution the marginal revenue product of capital must exceed its price. The same is true for labor. Only in the case of fuel will the marginal revenue product be equal to the factor price. Thus the firm must reduce output as the result of this form of regulation in period t.

Under this formulation it can similarly be shown that the firm subject only to an automatic fuel adjustment clause will expand output in the base period if it wishes to maximize a discounted stream of profit. It should be noted, however, that elimination of the uncertainty concerning the output effect in various periods is not sufficient to eliminate the confusion concerning the combination of capital with the other factors which will be encountered in section five of Chapter Three.

Cowing and Stevenson

Cowing and Stevenson conduct a rather complex, completely theoretical analysis of the impact of an automatic fuel adjustment clause on the firm's input choices [13]. The study assumes a "putty-clay" production technology with two inputs. The firm is initially able to choose among several technologies with various input mix requirements. However, each of these technologies is characterized by fixed proportions with respect to the variable input, which is fuel. Because there are only two inputs, capital and fuel, a technology can be specified in terms of a constant fuel to output ratio for sub-capacity levels of output. The authors proceed to examine the profit maximizing technology for a utility under several scenarios.

The first case considered is a simple two period model with no growth in demand. The price of fuel, and thus the price of output, as well as the cost of capital are assumed to be increasing functions of time. The only form of regulation imposed on the firm is the automatic fuel adjustment clause. The fuel adjustment clause is treated as a price regulation identical in form to the ones presented in Chapter Three of this paper. For periods beyond the base period, the output price is controlled according to the following equation:

$$P_t = P_1 + \phi(w_t F_t/Q_t - w_1 F_1/Q_1), \qquad 2.12$$

where

P is the price of output

ϕ is the percentage of fuel cost increases which can be passed on to consumers ($0 \leq \phi \leq 1$)

w is the per unit price of fuel

F is the quantity of fuel employed.

Subscripts denote time periods. The price of fuel in period one is exogenously determined by the regulators. Output for period one is, in turn, determined by the demand curve which is characterized by constant price elasticity. Because demand does not grow and output price increases over time, Q_1 represents capacity output.

The authors mathematically derive the regulated firm's profit maximizing marginal rate of technical substitution and compare it to the factor price ratio. Their conclusions are somewhat intuitively surprising. For an inelastic or mildly elastic demand function, the automatic fuel adjustment clause results in a fuel-using input bias. That is the firm will maximize the discounted stream of profit, by choosing a technology characterized by a higher fuel to output ratio. But other unexpected possibilities exist. For a sufficiently elastic demand, the authors contend that the firm could be induced to choose a more capital intensive technology and of course, the possibility for no input distortion is also present.

The authors fail to identify the real source of their rather surprising conclusions and it becomes somewhat lost in the mathematics. The possibility of a capital-using

bias is directly linked to one aspect of their treatment of the automatic fuel adjustment clause. The fuel adjustment constraint is treated as a strict equality. The capital using bias is possible only if the regulated price in period two would exceed the unconstrained profit maximizing price in that period for a firm which properly combined its productive inputs. If the regulated price in period two is interpreted as a ceiling rather than as an absolute price, so that equation 2.12 becomes a weak inequality, then the possibility of a capital-using bias is eliminated. This might be a more realistic treatment, and the possibility of a capital-using input distortion could then be ignored.

The second case considered is that of a firm subject to an automatic fuel adjustment clause, periodic rate reviews, input price inflation, no growth in demand and the objective of maximizing the present value of profits over an n-period horizon. Periodic rate reviews are introduced by requiring that, in a review period, the firm conforms to a rate of return constraint identical in form to that of Averch and Johnson [12]. The base price for the fuel adjustment clause is then the price set at the most recent rate hearing. In this case, the firm subject to both rate of return regulation and an automatic fuel adjustment clause unambiguously chooses a more fuel intensive technology than the firm subject only to rate of return regulation. It is not clear, however, whether the firm

subject to both forms of regulation will maximize profits by choosing a more or less fuel intensive technology than the unregulated utility. The precise outcome will, as the authors demonstrate, depend upon the rates of price inflation, the percentage of fuel prices which can be passed on, as well as the elasticity of demand. Various values are assigned to the critical parameters and the results are presented in table form.

Finally the case of fuel price inflation with demand growth is considered. The growth shift is assumed to be neutral so that

$$Q_t = c(1 + \delta)^t \, P_t^{-\eta} \qquad 2.13$$

where

δ is the growth rate

η is the price elasticity of demand

c is a constant

t is a time parameter

and other variables are as previously defined. It is also assumed that the capital stock cannot be increased beyond the initial period. It is the first time this assumption is required. Under the previous scenarios output was a decreasing function of time so that output in period one represented capacity output. It is now possible, given a sufficiently large growth rate for demand, to have output increasing over time despite a rising output price. In such a case, capacity is represented by Q_n.

The results are now somewhat mixed. For a moderate rate of growth in demand and a low rate of fuel price inflation, rate of return regulation with or without a fuel adjustment clause will result in a capital-using technology bias if demand is inelastic. Adding a fuel adjustment clause does, however, reduce the inefficiency. In some sense, the two forms of regulation can thus be said to offset one another. With mildly elastic demand, rate of return regulation without a fuel adjustment clause tends to be more efficient. Finally, in the case of highly elastic demand and a high rate of fuel price inflation, an automatic fuel adjustment clause alone results in relatively less input distortion than rate of return regulation and a fuel adjustment clause. This last result may be ruled out however if the regulated price in all periods is assumed to be less than the unconstrained profit maximizing output price.

Baron and DeBondt

In another purely theoretical paper, Baron and DeBondt set out to prove several propositions concerning the impact of an automatic fuel adjustment clause on the operation of the firm [14]. The analysis incorporates a two factor model with the production process characterized by a putty-clay technology. At time zero the firm can freely choose its fuel-capital mix but thereafter the ratio is fixed. The

ex-ante production function is also assumed to be homothetic, an assumption which is crucial for the proofs. It is also assumed that the firm is required to satisfy a demand function and the utility's objective is to maximize the expected discounted value of a stream of profits.

Basically, the model is developed in a three time period framework. In period one, the fuel price is c_1, output price is P_1, and profits are π_1. In period two, beginning at time t, the fuel price increases to c_2, but output price remains at P_1. Profits are equal to π_2. The length of period two is γ, the length of the collection lag under the fuel adjustment clause. In period three, the output price is increased to P_2, the fuel price remains at c_2, and profits are represented by π_3, the post price-adjustment profit.

The fuel adjustment clause is incorporated as a price constraint, by requiring that the following equation be satisfied.

$$P_2 = P_1 + (c_2 - c_1)f_1/Q_1(P_1) \qquad 2.14$$

where

P is the price of output

c is the per unit price of fuel

Q is the quantity of output produced

f is the quantity of fuel utilized.

Subscripts denote time periods as defined in the preceding paragraph.

Using the above model and assumptions, the authors state and prove three propositions. The first proposition, which focuses on uncertainty concerning the future price of fuel, states that if regulation is effective and a fuel price increase is anticipated with probability one $(Pr(c_2 \geq c_1) = 1$ and $Pr(c_2 \geq c_1) > 0)$, then the firm's optimal fuel-capital ratio will exceed the technically efficient fuel-capital ratio. Effective regulation requires only that the regulated price be less than the profit maximizing price for any chosen technology. This is the expected result and has been obtained with most models. Baron and DeBondt are, however, the first to demonstrate that the result holds even in the case of uncertainty over input prices.

The second part of proposition one states that if the expected value of c_2 is equal to c_1, then the firm will choose the proper technology if $\partial\pi_3/\partial P_2$ is constant in c_2, or in general if the functional form of π_3 is such that the covariance of $\partial\pi_3/\partial P_2$ and c_2 is equal to zero. The latter portion of proposition one again emphasizes the possibility of a fuel-intensive technology bias. In the case of uncertainty, such a bias could, in fact, be expected even if there were no expected increase in the price of fuel.

Proposition two introduces the possibility of using collection lags as a regulatory tool. Proposition two states that if a fuel price increase is anticipated, the firm's optimal fuel-capital ratio is a decreasing function

of γ. Again γ represents the length of the pass-through lag as explained above. This would indicate that a lag could be chosen to offset the fuel intensive technology bias discussed in proposition one. This proposition is intuitively plausible for the time framework under which it is developed. The longer the pass-through lag, the shorter the period of time over which the higher adjusted price will be enjoyed. This is, however, a rather unconventional treatment of the pass-through lag. In reality, the duration of the higher price may not be affected by the lag. The initiation of the new price may be merely postponed. The authors' treatment dramatically simplifies the analysis. Chapter Three demonstrates that additional assumptions may be necessary before a pass-through lag will unambiguously improve efficiency in all periods under a more conventional formulation.

Proposition three deals with the firm's incentive to choose the cheapest fuel sources. An alternative fuel source is introduced at this point, giving the firm the choice between the two. The two fuels are assumed to be perfect substitutes in production. Initially they have the same price, but at time t the second fuel's price is expected to rise relative to the first ($c_2^2 > c_2^1$). The fuel mix must be chosen ex-ante. Ex-post adjustment of the fuel mix is not considered.

Proposition three states that with non-decreasing returns to scale and a price P_2 at least as great as

marginal cost, there is no incentive to purchase the inefficient fuel for any collection lag between zero and infinity. With decreasing returns to scale and price no greater than marginal cost, the inefficient fuel will be utilized for small values of γ, the pass-through lag. Only the efficient fuel will be used for larger values of γ. The critical value γ, the one which separates the two situations, is mathematically derived in the paper. If Christensen and Greene are correct, however, few firms operate in a region of scale diseconomies and we need not worry about ex-ante biases in fuel choice [15].

Isaac

Isaac develops two alternative models for a fuel adjustment clause and analyzes the impact on the utility's choice of inputs under each of them [16]. In both models, the firm faces a standard neoclassical production function The firm chooses the capital quantity ex-ante and adjusts the fuel input ex-post. These are the only two inputs involved. The firm's demand function is also assumed to be price inelastic throughout. The price of fuel is assumed to be uncertain but non-decreasing over time. No storage is available to the firm or its customers.

In model A, the utility regulators act to insure that the firm earns a nonnegative amount of profits. A base price for output is set at time zero. If the realized price of fuel in period one is so high that negative

profits must result, then the regulators increase the period one price just sufficiently to eliminate losses. The input combination which maximizes the expected profit for a single production period for such a firm is mathematically derived.

Next, the author imposes a fuel adjustment clause on the firm. Two different types of fuel adjustment clauses are considered. They are formulated as follows.

$$\text{FAC 1:} \quad P_1 = P_0 + L_1(w_1 - w_0)/Q_0 \qquad 2.15$$

$$\text{FAC 2:} \quad P_1 = P_0 + (w_1L_1 - w_0L_0)/Q_0 \qquad 2.16$$

where

P is the price of output

Q is the quantity of output produced

L is the quantity of fuel employed

w is the per unit price of fuel

and subscripts denote time periods.

Neither formulation conforms to that of the NARUC which is utilized in this paper.

The authors continue by demonstrating that if the production function is quasi-concave and homothetic then in the case of no uncertainty the firm characterized by a fuel adjustment clause of either form will choose a capital-labor ratio which is less than or equal to the firm not subject to this form of regulation. They are unable, however, to extend their conclusions to the case of fuel price uncertainty.

Under model B the regulatory environment changes significantly. The firm is now subject to formal rate review and the fuel adjustment clause is implemented between these reviews. Also, the mechanism for activation of a nonnegative profit provision is eliminated. The base price is set in P_0. The firm has no control over this price and its formulation is exogenous. The output price for subsequent periods is determined according to a fuel adjustment clause of the form stated in equation 2.15. Finally, in period t, the firm must satisfy a rate of return constraint identical in form to that of Averch and Johnson [12]. The capital input is still fixed in quantity while fuel continues to be variable.

The conclusions are somewhat confusing. A firm subject to a fuel adjustment clause but no rate of return regulation will choose a more fuel intensive technology. Yet it cannot be determined whether a firm subject to both forms of regulation will choose a more or less fuel intensive technology than a firm subject only to the fuel adjustment clause. The problem is that the two regulatory constraints are interactive and their individual impacts are not additive. Again, it is meaningless to argue that the two regulatory tools offset each other in terms of their impact on input choice.

Scott

Scott takes a somewhat different approach to the analysis of the relationship between the fuel adjustment clause and input biases [7]. Scott argues that by increasing its utilization of fuel, the firm subject to an automatic fuel adjustment clause can reduce its profit variance. Furthermore, the reduction in profit variance can increase the market value of the firm.

The author utilizes a standard three factor production function. The heat rate, equal to F/Q, once chosen must remain constant. The regulatory climate is characterized by periodic rate reviews. Between these rate reviews, price is determined according to an automatic fuel adjustment clause. Price regulation can be summarized in two equations.

$$P_t = P_0 + \alpha f_t F_t / Q_t \qquad 2.17$$

and

$$P_0 = (sc_0 K_0 + w_0 L_0 + (1 - \alpha) f_0 F_0) / Q_0 \qquad 2.18$$

where

P is the output price

Q is the quantity of output produced

α is the percentage of a given cost change which can be passed on to the consumers

F is the quantity of fuel utilized

K is the quantity of capital utilized

L is the quantity of labor utilized

f is the per unit price of fuel

w is the per unit price of labor

c is the per unit price of capital goods

s is the allowed rate of return on capital.

The firm is also required to produce exactly that quantity which satisfies a downward sloping demand function in each period.

The above formulation for P_0 may appear somewhat strange since the allowed rate of return on capital is actually less than a. However, the formulation of P_0 is really without consequence for most of the analysis. The author is concerned only with profit variance in periods between rate reviews. For all practical purposes, it would appear that P_0 could be treated as any constant.

Using the above model, the author mathematically derives the profit variance for a given heat rate with and without the fuel adjustment clause. Again, only the periods between reviews are considered. It is demonstrated that if the price elasticity of demand is less than unity, then it can be inferred that an automatic fuel adjustment clause does, in fact, reduce the variance of profits.

Furthermore, according to the theory of capital-market equilibrium, risk can be measured by the covariance between the firm's profits and the profits of other firms. And if the firm's profit level is positively correlated with the market, then the risk associated with the firm

can be reduced by reducing the firm's own profit variance. Thus the automatic fuel adjustment clause should increase the market value of the firm to which it is applied.

The question of the impact on input choices is also addressed. It is shown that the automatic fuel adjustment clause reduced the fuel input's contribution to profit risk without affecting the contribution of the other two inputs. This is, of course, because a portion of fuel cost increases can be passed on to consumers. As a result, the firm will maximize its market value by using relatively more fuel and less capital and labor than in the absence of an automatic fuel adjustment clause.

Empirical Analyses

Gollop and Karlson

Gollop and Karlson hypothesize that a utility's average cost is a positive function of its ability to recover costs through an automatic fuel adjustment mechanism [17]. This hypothesis derives from two possible reactions by the firm. First, the firm may distort its input mix in response to its ability to immediately recover only higher fuel costs. Second, the firm may reduce efficiency in a factor neutral manner because the efficiency inducing characteristics of regulatory lag may be weakened.

Testing of the factor bias and neutral-inefficiency hypotheses requires evaluation of the firm's input

decisions (and resulting costs) at given input prices along a given isoquant. A translog specification of the cost function permits evaluation of the necessary partial derivatives and is thus employed. Additionally, the translog specification imposes no apriori restrictions on the elasticities of substitution and the economies of scale variable is allowed to vary with the level of output.

The cost function is modeled as

$$C = f(Q, P_L, P_K, P_F, h(FAM)) \qquad 2.19$$

where

Q is output produced

P_L is the per unit price of labor

P_K is the per unit price of capital

P_F is the per unit price of fuel

$h(FAM)$ is an unspecified function of the fuel adjustment mechanism

C is total generating cost.

Assuming that h has the exponential form e^{FAM}, the translog approximation to f is calculated. Next, taking the logarithmic partial derivatives of the translog cost function with respect to each factor price and applying Shephard's lemma, the required behavioral equations are derived. They are

$$W_i = a_i + \sum_j \gamma_{ij} (\ln P_j) + \gamma_{iQ}(\ln Q) + \gamma_{i,FAM}(FAM) \qquad 2.20$$

for i = labor, capital and fuel.

The variable w_i is also equal to $\partial \ln C / \partial \ln P_i$ or the ith input's share in total cost. The $\gamma_{i,FAM}$ parameters measure the factor bias due to the automatic fuel adjustment mechanism.

Since the fuel adjustment mechanism can also have a factor neutral effect on efficiency, the translog cost function is also included in the behavioral model. The w_K, w_F and translog cost equations are jointly estimated as a multivariate regression system using the Zellner efficient estimation method. The parameters of w_L are derived from the other equations.

The data set used includes 119 privately owned predominantly retail electric utilities that have generating capacity. All data come from Statistics on Privately Owned Electric Utilities in the United States and Steam-Electric Plant Construction Costs and Annual Production Expenses both published by the Federal Power Commission [18, 19]. Data adjustments are made following the method employed by Christensen and Greene [15]. FAM is defined as the ratio of recoverable costs to otherwise incurred costs. The sample period is 1970-1972 but the relationship is estimated separately for each year. Also, because of regional differences in fuel markets and the sensitivity of the chosen technology to input market characteristics, the data are disaggregated into four regional subsets. The Western subset is eliminated from further analysis as the primary power source is hydroelectric.

The results are mixed. There is no evidence that the presence of an automatic fuel adjustment mechanism leads to any bias in input selection or any increase in cost for the Gulf Region. Among the Northeast and Coal Belt Regions in 1971 and 1972, there is evidence of input bias induced by the fuel adjustment clause only in the Coal Belt in 1972. In this case, there is evidence of a modest shift toward fuel and capital and away from labor, the capital-fuel ratio is unaffected. There is, however, evidence of factor neutral inefficiency associated with the presence of a fuel adjustment mechanism for the Northeast region in 1971 and 1972 and for the Coal Belt in 1971. The input bias observed in the Coal Belt in 1972 apparently has no significant effect on costs.

The authors complete the analysis by estimating the elasticity of cost with respect to the fuel adjustment mechanism. They also estimate the effects of the magnitude of the fuel adjustment mechanism and the size of the firm on the cost elasticity. This is done for each firm in the Northeast and Coal Belt regions for 1971 and 1972. The results for a representative firm (sample mean) are reported. As expected, the cost elasticity estimates are positive, again indicating factor neutral inefficiency. Furthermore, the cost elasticities appear to be sensitive to the level of FAM $(\frac{\partial \ln AC/\partial \ln FAM}{\partial \ln FAM} > 0)$, and in some cases to firm size $(\frac{\partial \ln AC/\partial \ln FAM}{\partial \ln Q} > 0)$

The analysis appears to indicate that the automatic fuel adjustment clause, in some cases, imposes costs on society in the form of reduced efficiency. One can, however, contest this conclusion on several grounds. First of all, it must be recalled that the analysis establishes only correlation and not causation. If one reviews the objectives of the fuel adjustment clause from Chapter One, it appears plausible to conclude that the presence of the fuel adjustment clause may itself be a function of average costs. Those firms which, because of older capital equipment, or for other reasons, are less technically efficient may be the ones granted an automatic adjustment clause. Also, if inputs are not variable, as might be expected in the case of electric utilities, then firms which are stuck with a more fuel intensive technology would face the most serious threat from increasing fuel prices. It is reasonable to suspect that these firms would be more likely to receive protection in the form of an automatic fuel adjustment mechanism. In either case, the presence or magnitude of an adjustment clause and average costs would be correlated but no causation would be implied. Similarly, an apparent factor bias toward fuel could be correlated with the fuel adjustment mechanism even though the mechanism did not affect the input decision. These possibilities will be examined further in Chapter Four.

Atkinson and Halvorsen

In the empirical portion of their paper, Atkinson and Halvorsen test for relative and absolute efficiency in electric utilities subject to rate of return regulation and fuel adjustment clauses [11]. Relative efficiency implies, of course, that output is produced at minimum cost while absolute efficiency requires cost minimization and production of the proper quantity of output. The period used is 1973 and results indicate that neither relative nor absolute efficiency was attained that year.

The method employed to test for efficiency involves estimation of a normalized profit function and its associated factor demand functions. The analysis incorporates three inputs, capital, fuel and labor. The normalized profit function is specified to be of the translog form. The normalized profit function and the three factor demand functions are estimated using the iterative Zellner efficient estimation technique. Observations for 38 firms subject to fuel adjustment clauses in 1973 were included in the sample.

Let $\partial Q/\partial X_i = k_i P_i$ where X is a vector of inputs so that i is equal to capital, labor and fuel, Q is the quantity of output produced and P_i is the per unit price of factor i. Relative price efficiency requires that k_i be equal to k_j for all factor pairs. Absolute efficiency necessitates that $k_i = 1$ for all inputs. Tests for efficiency in both cases involved estimating the system of equations with and

without the appropriate restrictions. Letting λ equal the ratio of the maximum value of the likelihood function for the restricted equations to the maximum value for the unrestricted equations, $-2 \log \lambda$ is distributed asymptotically as a chi-square with degrees of freedom equal to the number of restrictions. Thus $-2 \log \lambda$ could be employed as a test statistic.

Most of the estimated parameters are statistically significant. The pseudo R^2 is equal to .94 indicating a very good fit. Relative price efficiency with respect to all inputs is rejected at the .01 level. And, of course, absolute efficiency can thus also be ruled out. With respect to pairs of inputs, relative efficiency is rejected at the .01 level for fuel and labor and for capital and labor. Relative efficiency for capital and fuel, however, cannot be rejected at the same significance level.

The results are far from surprising in light of the operating characteristics of the electric utility industry. The efficiency criteria which the authors used in evaluating performance are appropriate only in two cases. Case one requires that all inputs are perfectly variable in all periods so that the firm can immediately adjust its input mix in response to a change in factor prices or possibly to a change in output which would alter the marginal product ratios for the various factor pairs. Case two is that of a completely stagnant industry with respect to output as well as costs and prices, which would, of course, render the fuel

adjustment clause completely worthless as a regulatory tool and the entire issue could be dropped. Clearly neither case applies to the electric utility industry so that any meaningful interpretation of the results is difficult.

An alternative explanation for the so called "relative price inefficiency" is as follows. The price of fuel increased unexpectedly thus causing an apparent overutilization as the marginal product of fuel fell relative to its price, when in fact the input mix is not variable in the short run. The apparent overutilization of capital could also be the result of an increase in the price of capital or it could be the result of input distortions induced by rate of return regulation as hypothesized. This is not to say that the above interpretation is the correct one. The only intention is to point out that other explanations for the empirical observations might exist. Furthermore, there are serious problems associated with the application of the standard single period efficiency criteria to an industry where the input mix cannot be readily adjusted. In such a case, an assessment of efficiency requires an analysis of the entire expected time path of output as well as the entire expected time paths of input prices. It is, in fact, doubtful that any industry could pass the static tests for efficiency which the authors applied.

Kaserman and Tepel

In a primarily empirical paper, Kaserman and Tepel hypothesize that the direct correlation between output price and aggregate fuel costs may lead firms subject to automatic fuel adjustment clauses to pay a higher price for the aggregate fuel input than would be paid in the absence of such clauses [20]. There are two reasons why this might be the case. First of all, companies subject to fuel adjustment clauses may have less incentive to invest in searching for lower priced fuel sources. Second, given some variation in the rates at which specific fuel prices are increasing, those firms with adjustment clauses have a reduced incentive to switch their existing plants to the slower escalating fuels. Kaserman and Tepel examine the combined influence of the search and switch effects and then attempt to separate them.

Assumptions crucial to the analysis are first that the firm has some control over the fuel input price, and second that the rate of return constraint is not binding. The firm is assumed to be between rate hearings. The objective function for the firm is modeled as

$$\pi = R(\bar{K}, F, C) - rc\bar{K} - f(S, F\ C)P - gS \qquad 2.21$$

where

π is profit

R is total revenue from sales

$\overline{K}$ is the quantity of capital employed where capital is a fixed factor

F is the quantity of the aggregate fossil fuel input

C is the cleanliness of the fuel input

c is the per unit price of $\overline{K}$

r is the interest rate

S is the quantity of search and/or switching activity

g is the per unit cost of S

$f(S, F, C)$ is the per unit cost of $F(\partial f/\partial S < 0$, $\partial f/\partial F > 0$, $\partial f/\partial C > 0)$.

The firm subject to an automatic adjustment clause maximizes π subject to

$$P - fF/Q = P_b - f_bF_b/Q_b \qquad 2.22$$

where subscripts denote base period values and Q is the quantity of output produced. The firm not characterized by an adjustment clause maximizes π subject to

$$R(\overline{K}, F, C) = \overline{P}Q(\overline{K}, F, C) \qquad 2.23$$

where $\overline{P}$ is determined by the regulatory authority.

The Lagranian functions are then formed and the inverse demand functions for the fossil fuel input are derived for both the firm subject to an automatic fuel adjustment clause and the firm not subject to one. The base period values in equation 2.21 are assumed to be exogenously determined so

that the model collapses into a single period model. Of course, any potential impact on base period input choices due to the automatic adjustment clause are, by design, eliminated by this approach. It should be noted that the per unit cost of fuel is still not, as derived, unambiguously greater for firms with automatic fuel adjustment clauses. The ambiguity arises in part because these firms employ a greater amount of fuel, ceteris paribus, and thus have a greater incentive to hold down per unit fuel costs. The functions must thus be estimated.

Two additional assumptions are introduced to render the derived demand functions estimable. First, the output demand function is assumed to be characterized by constant elasticity. Second, the production function is assumed to be Cobb-Douglas. The parameters of the derived demand functions are empirically estimated using a single equation approach. The equation used is

$$f = \gamma_0 + \gamma_1(D_1)(R/F) + \gamma_2 C + \gamma_3(D_2)C + \gamma_4(D_1)Q + \gamma_5 F + \gamma_6(D_2)F + \gamma_7 N_1 + \gamma_8 N_2 + \gamma_9 N_3 + u \qquad 2.24$$

where

D_1 is a dummy variable for firms with adjustment clauses

D_2 is a dummy variable for firms without adjustment clauses

N_1, N_2, N_3 are regional dummy variables and all other variables are as previously defined.

The results lend some support to the model: γ_0, γ_5, γ_7, γ_8 and γ_9 are significant at the 99% confidence level. In addition γ_3 is significant at the 95% level. Furthermore, the signs of γ_1, γ_2 and γ_5 are consistent with the predicted signs (+, +, - respectively). While γ_4 and γ_6 do not have the predicted signs (both predicted to be negative), neither coefficient is significant. The R^2 is equal to .43.

Finally, the authors attempt to separate the switching and search effects, but with little success. Since the aggregate fuel price is the weighted sum of individual fuel prices, the aggregate fuel price differential (for firms subject to adjustment clauses as opposed to others) contains both a price and quantity effect. Because the sum of the switching effect and the search effect should equal the aggregate fuel price differential, only one of the component effects needs to be estimated. To estimate either, however, requires estimates of the prices paid for the individual fuel components under the two regulatory regimes. The basic equation (2.24) was thus re-estimated for the oil, coal and gas inputs separately. Unfortunately, the results are not tremendous. Several variables take on an unexpected sign, many variables become insignificant, and the R^2's are considerably lower. Thus little confidence can be placed in the results which indicate that all of the

inefficiency associated with the automatic adjustment clause results from the switching effect.

Again, one must question the treatment of the fuel adjustment clause. It is certainly plausible that the switching potential of the firm is considered by regulators when deciding whether to allow the firm to pass fuel cost increases on to its customers. It is quite possible then that the fuel adjustment clause is, at least in part, the result rather than the cause of what the authors interpret as switching inefficiencies. If this is the case, then a two equation simultaneous system should have been employed for estimating purposes where the dependent variable in the second equation would be the presence or absence of a fuel adjustment mechanism.

Stewart

Stewart is perhaps the first author to incorporate the recognition of limited ex-post factor substitution into an empirical analysis [21]. The author argues that, as a result of limited potential for substitution in existing plants, the most likely place to find an induced input bias is in newly constructed plants. And because of the time required to plan and construct a new facility, any factor bias would be expected to appear with a lag.

The model focuses on the firm's technology decision for a new plant. Capital is assumed to be a heterogeneous input which varies with respect to heat rate and capacity. The

price of a unit of capital can be expressed as a function of its attributes so that

$$P_K = P_K(\alpha, K) \qquad 2.25$$

where

P_K is the dollar cost of equipment per kilowatt of capacity

α is the heat rate of the equipment

K is the plant's capacity in kilowatts.

The ex-ante accounting function for a plant can then be expressed as

$$TC_t\ (\alpha, P_{Ft}, r, K, b) = \alpha\ 8760\ bKP_{Ft} + r_t P_K(\alpha, K)K \qquad 2.26$$

where

TC is total operating cost for year t

P_{Ft} is the price of fuel per Btu in year t

r_t is the money cost of capital including depreciation in year t

b is the plant load factor (percent of annual hours operated)

8760 is the number of hours in a year.

The author proceeds by assuming that the functional form for the cost of equipment is

$$P_K \gamma_0 (\alpha - 6000)^{-\gamma_1} K^{-\gamma_2}\ . \qquad 2.27$$

It is argued that 6000 is the lowest heat rate which is technologically feasible, and including the lower limit insures that costs approach infinity as the heat rate approaches its lower limit. Based on this functional form, a reduced form equation for the optimal heat rate is derived.

The equation which is estimated is

$$\ln(a_0 - 6000) = \beta_1 + \beta_2 \text{ DC} + \beta_3 \ln\left[\frac{b_0 P_{F0}}{r_0}\right] + \beta_4 \ln K_0 + \beta_5 \text{ FAC} + U \qquad 2.28$$

where

a_0 is the observed heat rate of the new plant in the first full year of operation

DC is a dummy variable equal to one only if the plant is coal-fired

FAC is a fuel adjustment clause variable

U is a standard residual

and other variables are as previously defined with the subscript zero indicating values for the initial period.

Equation 2.28 is estimated using ordinary least squares. The data set includes nineteen plants which began operations in 1974 and 1975. Two different formulations for the FAC variable are used. The first is a dummy variable for the presence of an adjustment mechanism. The second formulation is a continuous variable, the ratio of recoverable costs

to otherwise incurred costs. The second is the same formulation which is employed by Gollop and Karlson [17]. The R^2 is equal to .61 for the first model and .68 for the second, indicating a fair amount of explanatory power in both cases. The FAC variable is insignificant under the first formulation but significant at the 95 percent level under the second formulation. The coefficient on relative prices, β_3, is negative and significant at the 95 percent level in both cases.

The crucial element with respect to this analysis is timing. The sample contains plants whose designs were finalized in 1971, the assumed planning period. These plants came on line in 1974 or 1975. They were designated as being subject or not subject to an adjustment mechanism based on their status in 1971. Yet by 1978, the fuel adjustment clause was almost universally applied. It may not be completely reasonable to argue that firms were completely unable to anticipate the surge in popularity for this regulatory tool. It would be interesting to know if the inclusion of a separate independent variable for the length of time to the granting of an adjustment mechanism would improve the model's explanatory power. This should be the case if regulatory expectations enter the decision process at the planning stage.

It is also interesting to note that the FAC, when modelled as a dummy variable, is statistically insignificant. As discussed in Chapter One, fuel adjustment clauses

as well as the regulation of such clauses vary dramatically from state to state as well as from firm to firm within a single state. This empirical result might indicate that interclause differences offset the efficiency incentives to such an extent that the lumping together of all clauses is meaningless. If this is the case, then it would indicate that significant improvements in efficiency could be brought about by reformulation rather than elimination of the adjustment clause.

Conclusions

Few generalizations can be made concerning the theoretical models of the impact of the fuel adjustment clause on efficiency. For the majority, the conclusions are intuitively appealing. That is, there is reason to believe that this regulatory tool leads to an overutilization of the fuel input.

As with many theoretical topics, the conclusions in some cases are very dependent on the assumptions. The transformation of the fuel adjustment mechanism from a price constraint into a revenue constraint serves, for example, to eliminate some ambiguities concerning the impact on output. Similarly, the focusing of attention on only those periods when the fuel adjustment clause is binding reduces uncertainty concerning the direction of distortion in the input ratios when these ratios must remain fixed. The destruction of concrete results may be a partial

explanation for the fact that not a single paper addresses the possibility of an induced input distortion in the review period attributable to the fuel adjustment mechanism.

By comparison, the theoretical analysis presented in Chapter Three appears simple and straightforward. The number of assumptions is kept to a minimum and the mathematics is elementary. In many cases, concrete results are lacking, but the source of the associated uncertainties is clarified. Finally, the modelling of the fuel adjustment mechanism is based strictly on the NARUC's statement concerning the actual application of this regulatory tool [2].

The results of the empirical studies are also mixed. There is evidence to support the contention that the automatic fuel adjustment clause is associated with reduced efficiency of one form or another. Yet there is no firm indication that this regulatory tool causes inefficiency. The problem, again, is that the presence of an adjustment mechanism is treated as exogenously determined when in fact it may be determined by some aspects of the firm's cost structure.

There are also problems in defining efficiency criteria as it is not reasonable to treat all inputs as variable. Finally, there is no summary measure of the cost of any inefficiency which could be utilized by policy makers in evaluating the costs and benefits of this form of regulation. Work in all of these areas will be necessary before a comprehensive evaluation of the automatic fuel adjustment

mechanism as a tool for electric utility regulation can be completed.

CHAPTER THREE

THEORETICAL ANALYSIS

Introduction

The purpose of this chapter is to develop an analytic framework within which to examine the impact of the automatic fuel adjustment clause on efficiency. The first step is to address the question of what exactly is meant by 'efficient performance." Various types of inefficiency can then be differentiated and their sources, including the impact of the automatic fuel adjustment clause, can be examined.

Efficiency must be defined relative to some objective, and the goal of the firm is generally assumed to be the maximization of profit. In the multi-period case, the firm's objective is the maximization of the discounted value of a stream of profits. An unregulated competitive firm thus is said to be operating efficiently when it is maximizing profit subject to the constraints imposed upon it. But what are those constraints?

The first constraint facing a firm is its production function. The production function, which defines the maximum output obtainable from a given bundle of inputs, is

determined by the state of the arts or technology. A firm which fails to maximize output, given its input bundle and its production function, is said to be technically inefficient. It is operating beneath its production frontier and is thus wasting resources.

The second constraint facing the firm is a vector of input prices. The input prices, together with the production function, determine the firm's cost function. The cost function defines the minimum cost at which a given level of output can be produced. A firm which fails to produce its output at minimum cost is said to be cost inefficient. It is operating above its cost frontier.

There are several sources of cost inefficiency. Obviously, a firm which wastes resources by producing beneath its production frontier cannot be minimizing costs. Thus, technical inefficiency is a source of cost inefficiency. It is not generally the only source, however, so that technical efficiency is a necessary condition but not a sufficient condition for cost efficiency. The firm must also combine the various factors in a cost minimizing manner. Failure to combine resources properly, given their prices, is usually referred to as relative price inefficiency, or factor-biased inefficiency.

The third constraint facing the firm is its demand function. The demand function expresses the maximum per

unit price at which various quantities of the firm's output can be sold. A firm which fails to choose the profit maximizing output is said to be characterized by absolute price inefficiency or economic inefficiency. Absolute price efficiency requires that the firm attain its objective of profit maximization. Technical efficiency and cost efficiency are thus necessary conditions for economic efficiency. Additionally, the firm is required to choose the proper output.

There is little evidence that the goal of the regulated firm is any different from that of the unregulated firm, namely, profit maximization. Regulation simply imposes additional constraints on the firm's operation. Yet the regulated firm's performance is generally not evaluated relative to its own profit maximization conditions but rather relative to a competitive firm's optimal behavior. Thus discussion concerning the efficiency reducing aspects of regulatory policies centers on the regulated firm's induced deviation from the unregulated firm's optimal or efficient performance. The reason for this apparent inconsistency is simple. A competitive equilibrium is Pareto efficient and thus provides an absolute standard for comparison in terms of social welfare.

Having briefly outlined a basic framework, the effect on firm behavior of the imposition of an automatic fuel adjustment clause will be examined under various scenarios. The behavior of the firm subject to this type of regulation

will then be compared to the behavior of an unregulated firm. In this manner, the impact of the automatic fuel adjustment clause on efficiency can be deduced.

The Model

The analysis will incorporate a standard well behaved neoclassical production function with three inputs.

$$Q_t = Q\,(F_t,\ K_t,\ L_t) \text{ with } Q\,(0,\ K_t,\ L_t) = Q\,(F_t,\ 0,\ L_t) = Q\,(F_t,\ K_t,\ 0) = 0 \text{ and } \partial Q/\partial F_t,\ \partial Q/\partial K_t,\ \partial Q/\partial L_t > 0. \qquad 3.1$$

Here Q is the quantity of power produced by the firm and F, K, L measure the fuel, capital and labor inputs respectively. The subscripts denote the time period.

The firm faces a downward sloping demand curve

$$Q_t = P_t^{-\eta} \text{ where } \partial Q_t/\partial P_t < 0. \qquad 3.2$$

The price elasticity of demand, η, is assumed to be constant across price and time. Demand growth will be introduced into the model shortly.

The input markets are assumed to be perfectly competitive and the per unit costs of F, K and L in period t are f_t, r_t and w_t respectively. An additional simplifying assumption will be incorporated initially. It will be assumed that all input quantities are completely variable in

each time period. The exceedingly unrealistic assumption will be relaxed subsequently.

The Competitive Firm

Since the competitive firm's profit maximizing behavior is to serve as the standard for comparison, its operation must be examined more closely. Its objective function can be written as

$$\text{Max} \sum_{t=1}^{n} b_t P_t Q_t - \sum_{t=1}^{n} b_t \ (r_t K_t + w_t L_t + f_t F_t) \qquad 3.3$$

where b_t is the discount factor for period t. In the case of a constant discount rate R,

$$b_t = 1/(1+R)^{t-1} \qquad 3.4$$

so that $0 < b_t \leq 1$ for all t. The firm is constrained by its input prices (f_t, w_t and r_t), as well as by its production and demand functions. Its objective function must be maximized subject to

$$Q_t \leq Q \ (F_t, K_t, L_t) \qquad 3.5$$

and

$$Q_t = P_t^{-\eta} \quad \text{for all t.} \qquad 3.6$$

Because of the simplifying assumptions, profit in each period is, for the moment, completely independent of the firm's behavior in all other periods. The firm's objective reduces to one of profit maximization in each period. And again, profit maximization requires that the proper output be chosen and that costs be minimized for that output.

Cost minimization requires, first of all, technical efficiency so that the production constraint must be binding or

$$Q_t = Q\ (F_t,\ K_t,\ L_t) \quad \text{for all } t. \qquad 3.7$$

Additionally, factors must be combined in the cost minimizing manner. The optimal combination of inputs requires that

$$MPL_t/w_t = MPK_t/r_t = MPF_t/f_t \quad \text{for all } t \qquad 3.8$$

where

$$MPL_t = \partial Q_t/\partial L_t,\ MPK_t = \partial Q_t/\partial K_t,\ MPF_t = \partial Q_t/\partial F_t. \qquad 3.9$$

This condition is clearly equivalent to requiring that

$$MPL_t/MPK_t = w_t/r_t,\ MPL_t/MPF_t = w_t/f_t, \text{ and}$$
$$MPK_t/MPF_t = r_t/f_t \quad \text{for all } t. \qquad 3.10$$

And finally, profit maximization requires that the optimal output be produced and sold. This condition can be expressed as

$$MPF_t \cdot P_t (1 - 1/\eta) = f_t, \; MPK_t \cdot P_t (1 - 1/\eta) = r_t$$

$$\text{and } MPL_t \cdot P_t (1 - 1/\eta) = w_t \quad \text{for all } t. \qquad 3.11$$

Again, the above profit maximizing conditions must be satisfied in each period. Assuming that the corresponding profit in each period is nonnegative, these conditions are individually necessary and jointly sufficient for profit maximization in each period. And given the simplifying assumptions currently in effect, profit maximization in each period is necessary and sufficient for maximization of the discounted stream of profits.

Having established a standard for comparison, the behavior of the regulated firm can now be examined. This paper will primarily focus on relative price inefficiency or the failure to properly combine the various inputs. The analysis involves comparison of the regulated firm's profit maximizing input combinations with the unregulated firm's efficient performance. This process will be repeated for several different scenarios. The effect of the automatic fuel adjustment clause on technical efficiency as well as on economic efficiency will be briefly discussed.

The Regulated Firm

The Firm Subject Only to an Automatic Fuel Adjustment Clause

An automatic fuel adjustment clause can be incorporated in the model by imposing an additional constraint upon the firm.

$$P_t \leq P_1 + \phi(f_t F_t / Q_t - f_1 F_1 / Q_1) \quad \text{for } t \geq 2. \qquad 3.12$$

All variables are as previously defined and ϕ is the proportion of a fuel cost increase which the firm is permitted to pass on to the consumer. Thus, it can be reasonably assumed that $0 < \phi \leq 1$. P_1 is the base period's price.

Profits in the various time periods may no longer be completely independent. The results of a two period model can be easily extended, however, as only two categories of time periods are involved--base periods and fuel adjustment periods. For a two period model, the objective function is

$$\text{Max } (P_1Q_1 - w_1L_1 - f_1F_1 - r_1K_1) + b(P_2Q_2 - w_2L_2 - f_2F_2 - r_2K_2), \qquad 3.13$$

For the moment the only regulatory constraint facing the firm is the fuel adjustment constraint in period two. The relevant Lagrangian function is

$$£ = (P_1Q_1 - w_1L_1 - f_1F_1 - r_1K_1) + b(P_2Q_2 - w_2L_2 - f_2F_2 - r_2K_2) - \lambda_2(P_2 - P_1 - \phi(f_2F_2/Q_2 - f_1F_1/Q_1)). \qquad 3.14$$

The impact of the automatic fuel adjustment clause on relative price efficiency in the base period can be ascertained by examining the ratios of the first derivatives of the Lagrangian function.

$$\partial £/\partial L_1 = Q_1 \cdot \partial P_1/\partial Q_1 \cdot \partial Q_1/\partial L_1 + P_1 \cdot \partial Q_1/\partial L_1 - w_1 - \lambda_2(- \partial P_1/\partial Q_1 \cdot \partial Q_1/\partial L_1 - \phi f_1F_1/Q_1{}^2 \cdot \partial Q_1/\partial L_1) \qquad 3.15$$

$$\partial £/\partial K_1 = Q_1 \cdot \partial P_1/\partial Q_1 \cdot \partial Q_1/\partial K_1 + P_1 \cdot \partial Q_1/\partial K_1 - r_1 - \lambda_2(- \partial P_1/\partial Q_1 \cdot \partial Q_1/\partial K_1 - \phi f_1F_1/Q_1{}^2 \cdot \partial Q_1/\partial K_1) \qquad 3.16$$

$$\partial £/\partial F_1 = Q_1 \cdot \partial P_1/\partial Q_1 \cdot \partial Q_1/\partial F_1 + P_1 \cdot \partial Q_1/\partial F_1 - f_1 - \lambda_2(- \partial P_2/\partial Q_1 \cdot \partial Q_1/\partial F_1 - \phi f_1F_1/Q_1{}^2 \cdot \partial Q_1/\partial F_1 + \phi f_1/Q_1) \qquad 3.17$$

Setting equations 3.15 and 3.16 equal to zero and solving for the ratio of the marginal product of labor to the marginal product of capital yields the following expression:

$$MPL_1/MPK_1 = w_1/r_1. \qquad 3.18$$

Using equations 3.15 and 3.17 and repeating the procedure, the following equation is derived:

$$MPL_1/MPF_1 = w_1/f_1(1 + \lambda_2\theta/Q_1). \qquad 3.19$$

And finally, equations 3.16 and 3.17 can be set equal to zero and their ratio simplified to produce the following result.

$$MPK_1/MPF_1 = r_1/f_1(1 + \lambda_2\theta/Q_1). \qquad 3.20$$

It is apparent from equation 3.18 that the firm subject only to the automatic fuel adjustment clause will maximize profits by combining capital and labor in the same proportion as the unregulated competitive firm, or efficiently.[1] Fuel, however, will be improperly combined with the other two factors. If λ_2 is positive, then from equation 3.19 and 3.20 it is clear that profit maximization requires the firm to combine inputs in such a manner that the ratio of the marginal product of fuel to the marginal product of either of the other inputs will exceed the ratio of the price of fuel to the price of either of the other factors. The problem in this period would be one of fuel underutilization. Costs could be reduced by increasing the usage of fuel relative to labor and capital in period one.

While a nonpositive value for lambda, the Lagrange multiplier, is mathematically feasible, the possibility

merits little concern. Recalling that lambda is merely the partial derivative of the Lagrangian function with respect to the constraint constant, it is clear that lambda can take on a negative value only if the regulated price in period two exceeds the profit maximizing price for the same period.

The process can be repeated for the second period. The partial derivatives of the Lagrangian function with respect to each of the second period's inputs must be obtained.

$$\partial \pounds/\partial L_2 = b(Q_2 \cdot \partial P_2/\partial Q_2 \cdot \partial Q_2/\partial L_2 + P_2 \cdot \partial Q_2/\partial L_2 - w_2) - \lambda_2(\partial P_2/\partial Q_2 \cdot \partial Q_2/\partial L_2 + \phi f_2 F_2/Q_2^{2} \cdot \partial Q_2/\partial L_2) \tag{3.21}$$

$$\partial \pounds/\partial K_2 = b(Q_2 \cdot \partial P_2/\partial Q_2 \cdot \partial Q_2/\partial K_2 + P_2 \cdot \partial Q_2/\partial K_2 - r_2) - \lambda_2(\partial P_2/\partial Q_2 \cdot \partial Q_2/\partial K_2 + \phi f_2 F_2/Q_2^{2} \cdot \partial Q_2/\partial K_2) \tag{3.22}$$

$$\partial \pounds/\partial F_2 = b(Q_2 \cdot \partial P_2/\partial Q_2 \cdot \partial Q_2/\partial F_2 + P_2 \cdot \partial Q_2/\partial F_2 - f_2) - \lambda_2(\partial P_2/\partial Q_2 \cdot \partial Q_2/\partial F_2 + \phi f_2 F_2/Q_2^{2} \cdot \partial Q_2/\partial F_2 - \phi f_2/Q_2) \tag{3.23}$$

Again, the above partial derivatives can be set equal to zero, and ratios constructed and simplified to yield the following necessary conditions for profit maximization.

$$MPL_2/MPK_2 = w_2/r_2 \tag{3.24}$$

$$MPL_2/MPF_2 = w_2/f_2(1 - \lambda_2\phi/bQ_2) \qquad 3.25$$

$$MPK_2/MPF_2 = r_2/f_2(1 - \lambda_2\phi/bQ_2) \qquad 3.26$$

From equation 3.24 it is evident that the firm will combine labor and capital in the efficient proportion again in period two. Equations 3.25 and 3.26 reveal that fuel will again be improperly combined with both of the other inputs. The problem in period two, however, is one of fuel overutilization relative to capital and labor. Since λ_2, ϕ, b, and Q_2 are all positive, the ratio of the marginal product of fuel to its price will be less than the same ratio for the other inputs. Costs could be reduced in this period by reducing the usage of fuel relative to the other inputs.

In period one, the magnitude of the input distortion depends on the value of $\lambda_2\phi/Q_1$ while in period two the size of the distortion is determined by the value of $\lambda_2\phi/bQ_2$. Clearly, the greater is ϕ, that is the larger is the proportion of fuel price increases which can be passed on to the consumer, the greater will be the input distortion in both periods.

The relationship between the discount factor, b, and the magnitude of the distortion is not as readily apparent. The relationship is quite clear on intuitive grounds, however, as λ_2 is the increase in the discounted value of

profits associated with a one unit relaxation of the regulatory constraint. It is thus plausible to conclude that

$$\partial\lambda_2/\partial b > 0 \tag{3.27}$$

Furthermore, with no restriction on P_1, any input distortion in period one reduces that period's profit. But the gain from an input distortion in either period does not accrue until period two. So a decrease in the discount factor should clearly reduce the attractiveness of any input distortion in either period, as the discounted benefit will be diminished. Partial differentiation of period two's distortion with respect to b yields the following.

$$\partial(\phi\lambda_2/bQ_2)/\partial b = \phi/bQ_2 \cdot \partial\lambda_2/\partial b - \phi\lambda_2/b^2Q_2. \tag{3.28}$$

This expression can be simplified to

$$\partial(\phi\lambda_2/bQ_2)/\partial b = \phi/bQ_2(\partial\lambda_2/\partial b - \lambda_2/b). \tag{3.29}$$

And since it is known that an increase in the discount factor is expected to increase the magnitude of the distortion, it can be deduced that

$$\partial\lambda_2/\partial b > \lambda_2/b. \tag{3.30}$$

Finally, the magnitude of the distortion in both periods is an increasing function of λ_2, the Lagrange multiplier. And again,

$$\lambda_2 = \partial\pi/\partial(P_2 - P_1 - \phi(f_2F_2/Q_2 - f_1F_1/Q_1)) \quad . \qquad 3.31$$

Clearly, the value of lambda depends on the relationship between demand elasticity and cost elasticity for the two periods. The determinants of lambda will be more precisely examined in a later section, following the relaxation of several assumptions.

The Firm Subject to an Automatic Fuel Adjustment Clause and Rate of Return Regulation

The previous scenario dealt with a firm subject only to an automatic fuel adjustment clause. The price charged in period one was constrained only by the demand function. This example will address a somewhat more realistic question. The effect of the imposition of an automatic fuel adjustment clause on a firm subject to rate of return regulation will be examined.

First it should be noted that an automatic fuel adjustment clause is meaningless if a rate hearing is to be conducted each period. Generally, a rate review takes place periodically at which point the price is set to conform to a specified rate of return. The price is then allowed to fluctuate in interim periods according to the automatic fuel adjustment clause. Since only two types of periods are

involved, a two period model can be initially employed for illustrative purposes.

In order to separate the impacts of the two regulatory policies, the input choice for a firm subject only to rate of return regulation will first be analyzed. This result will then be compared to the behavior of a firm maximizing profits subject to both types of regulation. The assumptions from the previous section concerning variability and divisibility of inputs, stable demand and competitive input markets will remain in tact.

Averch and Johnson first presented an analysis indicating that firms subject to rate of return regulation might improperly combine resources from a social point of view [12]. Specifying period one to be the review period, the rate of return constraint can be incorporated into this analysis in a similar manner by requiring that

$$P_1Q_1 - W_1L_1 - E_1F_1 \leq sK_1, \qquad 3.32$$

where s is the "fair" rate of return on capital set by the regulators. The constraint can be rewritten as

$$P_1 - (W_1L_1 + E_1F_1 + sK_1)/Q_1 \leq 0. \qquad 3.33$$

The price resulting from a rate review would prevail until the next review. Since period two is, by assumption, a

nonreview period, the price in period two would be equal to period one's price.

If this is the only form of regulation then the relevant Lagrangian function is

$$\mathcal{L} = P_1Q_1 - w_1L_1 - f_1F_1 - r_1K_1 + b(P_2Q_2 - w_2L_2 - f_2F_2 - r_2K_2) - \lambda_1(P_1 - (w_1L_1 + f_1F_1 + sK_1)/Q_1) - \lambda_2(P_2 - P_1). \qquad 3.34$$

The Lagrangian must then be differentiated with respect to each of the independent variables.

$$\partial\mathcal{L}/\partial L_1 = Q_1 \cdot \partial P_1/\partial Q_1 \cdot \partial Q_1/\partial L_1 + P_1 \cdot \partial Q_1/\partial L_1 - w_1 - \lambda_1(\partial P_1/\partial Q_1 \cdot \partial Q_1/\partial L_1 + (w_1L_1 + f_1F_1 + sK_1)/Q_1^2 \cdot \partial Q_1/\partial L_1 - w_1/Q_1) - \lambda_2(\partial P_1/\partial Q_1 \cdot \partial Q_1/\partial L_1) \qquad 3.35$$

$$\partial\mathcal{L}/\partial K_1 = Q_1 \cdot \partial P_1/\partial Q_1 \cdot \partial Q_1/\partial K_1 + P_1 \cdot \partial Q_1/\partial K_1 - r_1 + \lambda_1(\partial P_1/\partial Q_1 \cdot \partial Q_1/\partial K_1 + (w_1L_1 + f_1F_1 + sK_1)/Q_1^2 \cdot \partial Q_1/\partial K_1 - s/Q_1) - \lambda_2(\partial P_1/\partial Q_1 \cdot \partial Q_1/\partial K_1) \qquad 3.36$$

$$\partial\mathcal{L}/\partial F_1 = Q_1 \cdot \partial P_1/\partial Q_1 \quad \partial Q_1/\partial F_1 + P_1 \cdot \partial Q_1/\partial F_1 - f_1 + \lambda_1(\partial P_1/\partial Q_1 \cdot \partial Q_1/\partial F_1 + (w_1L_1 + f_1F_1 + sK_1)/Q_1^2 \cdot \partial Q_1/\partial F_1 - f_1/Q_1) - \lambda_2(\partial P_1/\partial Q_1 \cdot \partial Q_1/\partial F_1) \qquad 3.37$$

The effect of rate of return regulation on allocative efficiency can again be demonstrated by setting the above derivatives equal to zero and constructing ratios for the marginal products of each pair of inputs

$$MPL_1/MPK_1 = (w_1 - \lambda_1 w_1/Q_1)/(r_1 - \lambda_1 s/Q_1) \tag{3.38}$$

$$MPL_1/MPF_1 = w_1/f_1 \tag{3.39}$$

$$MPK_1/MPF_1 = (r_1 - \lambda_1 s/Q_1)/(f_1 - \lambda_1 f_1/Q_1). \tag{3.40}$$

It is apparent from equation 3.39 that labor and fuel will be efficiently combined in the first period by the profit maximizing firm subject only to rate of return regulation. There is evidence though that capital will not be combined in proper proportion with either fuel or labor. Equations 3 38 and 3 40 can be rewritten to clarify the input bias.

$$MPL_1/MPK_1 = w_1(1 - \lambda_1/Q_1)/r_1(1 - \lambda_1/Q_1 \cdot s/r_1) \tag{3.41}$$

$$MPK_1/MPF_1 = r_1(1 - \lambda_1/Q_1 \cdot s/r_1)/f_1(1 - \lambda_1/Q_1) \tag{3.42}$$

It has been argued that $1 - \lambda_1/Q_1$ is positive.[2] Thus if λ_1 and λ_2 are positive and s is greater than r, then capital will be overutilized relative to both fuel and labor. Again, λ_1 and λ_2 will be positive as long as the regulated price in both periods is less than the profit maximizing price. And s will exceed r_1 if the regulated rate of return exceeds the actual cost of the capital in period one.

The rate of return constraint will have no impact on allocative efficiency in the second period as it is a non-review period and thus the rate of return constraint is not binding. Since all inputs are assumed to be completely variable, the firm would adjust its input mix in period two to minimize costs. The ratio of marginal product to price would thus be equated for all factors in period two. The firm would combine inputs efficiently.

The fuel adjustment clause can now be added to the model. The firm is now subject to an automatic fuel adjustment clause and rate of return regulation. A rate review is conducted in period one so that the rate of return constraint is binding for that period. The price is allowed to vary according to the fuel adjustment clause in period two. The relevant Lagrangian function becomes

$$\begin{aligned} \pounds = {} & P_1Q_1 - w_1L_1 - f_1F_1 - r_1K_1 + b(P_2Q_2 - w_2L_2 - f_2F_2 \\ & - r_2K_2) - \lambda_1(P_1 - (w_1L_1 + f_1F_1 + sK_1)/Q_1) - \lambda_2(P_2 - P_1 \\ & - \phi(f_2F_2/Q_2 - f_1F_1/Q_1)) \end{aligned} \qquad 3.43$$

where all variables are as previously defined.

The Lagrangian function must again be differentiated with respect to each input. The review period will be examined first.

$$\partial \pounds/\partial L_1 = Q_1 \cdot \partial P_1/\partial Q_1 \cdot \partial Q_1/\partial L_1 + P_1 \cdot \partial Q_1/\partial L_1 - w_1 - \lambda_1(\partial P_1/\partial Q_1 \cdot \partial Q_1/\partial L_1 + (w_1L_1 + f_1F_1 + mK_1)/Q_1^2 \cdot \partial Q_1/\partial L_1 - w_1/Q_1) - \lambda_2(- \partial P_1/\partial Q_1 \cdot \partial Q_1/\partial L_1 - \phi f_1F_1/Q_1^2 \cdot \partial Q_1/\partial L_1) \qquad 3.44$$

$$\partial \pounds/\partial K_1 = Q_1 \cdot \partial P_1/\partial Q_1 \cdot \partial Q_1/\partial K_1 + P_1 \cdot \partial Q_1/\partial K_1 - r_1 - \lambda_1(\partial P_1/\partial Q_1 \cdot \partial Q_1/\partial K_1 + (w_1L_1 + f_1F_1 + mK_1)/Q_1^2 \cdot \partial Q_1/\partial K_1 - m/Q_1) - \lambda_2(- \partial P_1/\partial Q_1 \cdot \partial Q_1/\partial K_1 - \phi f_1F_1/Q_1^2 \cdot \partial Q_1/\partial K_1) \qquad 3.45$$

$$\partial \pounds/\partial F_1 = Q_1 \cdot \partial P_1/\partial Q_1 \cdot \partial Q_1/\partial F_1 + P_1 \cdot \partial Q_1/\partial F_1 - f_1 - \lambda_1(\partial P_1/\partial Q_1 \cdot \partial Q_1/\partial F_1 + (w_1L_1 + f_1F_1 + mK_1)/Q_1^2 \cdot \partial Q_1/\partial F_1 - f_1/Q_1) - \lambda_2(- \partial P_1/\partial Q_1 \cdot \partial Q_1/\partial F_1 - \phi f_1F_1/Q_1^2 \cdot \partial Q_1/\partial F_1 + \phi f_1/Q_1) \qquad 3.46$$

These derivatives can be set equal to zero and ratios formed to examine the firm's profit maximizing input combinations for period one.

$$MPL_1/MPK_1 = w_1(1 - \lambda_1/Q_1)/r_1(1 - \lambda_1/Q_1 + m/r_1) \qquad 3.47$$

$$MPL_1/MPF_1 = w_1(1 - \lambda_1/Q_1)/f_1(1 - \lambda_1/Q_1 + \lambda_2\phi/Q_1) \qquad 3.48$$

$$MPK_1/MPF_1 = r_1(1 - \lambda_1/Q_1 \cdot s/r_1)/(F_1(1 - \lambda_1/Q_1 + \lambda_2\phi/Q_1)) \qquad 3.49$$

The procedure does not have to be repeated to determine the period two impact of imposing an automatic fuel adjustment clause on a firm already subject to rate of return regulation. The effect of the automatic fuel adjustment clause on the combining of inputs in the second, or nonreview period, will be the same whether or not the firm faces a rate of return constraint in period one. The result stems from the fact that the rate of return constraint is not binding in nonreview periods and the assumption that inputs are completely variable in each period. The period two input distortions will be the same as those indicated by equations 3.24 and 3.26.

The full impact of imposing an automatic fuel adjustment clause on a firm subject to rate of return regulation can now be evaluated. If the regulated price for the nonhearing period is less than that period's profit maximizing price, then λ_2 will be positive. Comparison of equation 3.49 with equation 3.43 reveals that the automatic fuel adjustment clause will cause further distortion in the combining of capital and fuel. The effect on the firm's profit maximizing combination of capital and fuel is intuitively clear. The automatic fuel adjustment clause introduces the incentive to underutilize fuel in the base period.

An examination of equation 3.49 reveals that the firm will continue to overutilize capital if the following condition is satisfied:

$$1 - \lambda_1/Q_1 + \lambda_2\phi/Q_1 > 1 - \lambda_1/Q_1 \cdot s/r_1 \qquad 3.50$$

Assuming again that regulatory constraints are binding in both periods, so that λ_1 and λ_2 are positive, equation 3.50 can be rewritten as follows.

$$\lambda_1 - \lambda_2\phi < \lambda_1 \cdot s/r_1 \qquad 3.51$$

Since ϕ is positive and s exceeds r, clearly the firm will continue to utilize too much capital relative to fuel. Furthermore, the firm will combine capital and fuel in a less efficient manner in the base period for a given output as equation 3.42 exceeds equation 3.49.

The impact of the introduction of the fuel adjustment clause on the relative usage of the other factors must also be examined. Equation 3.39 indicated that fuel and labor would be properly combined under rate of return regulation. Following the introduction of an automatic fuel adjustment clause, this is no longer the case. Equation 3.48 clearly demonstrates that the firm subject to both forms of regulation will overutilize labor relative to fuel in the base period. Finally, a comparison of equation 3.47 with equation 3.41 indicates that the automatic fuel adjustment

clause does not affect the overutilization of capital relative to labor in period one, for a given output.

With variable inputs, the firm subject only to rate of return regulation would combine inputs in a cost minimizing or socially optimal manner in nonreview periods. The firm subject to both forms of regulation will be characterized by the distortions indicated in equations 3.24 through 3.26 for period two or the nonreview period. All of the input distortion in the second period is attributable to the automatic fuel adjustment clause. The rate of return constraint has an impact only in period one.

The above results are somewhat confusing in light of the recent literature. It is frequently asserted that the impact of the automatic fuel adjustment clause on the combining of inputs will offset the effects of rate of return regulation [11]. This would imply that the firm subject to both forms of regulation would combine inputs more efficiently than a firm subject to only one form of regulation. If input quantities are readily variable, this is not necessarily true for period one. The capital-fuel ratio is further distorted, while a new distortion is introduced into the labor-fuel ratio. Furthermore, new distortions arise in nonreview periods when inputs would be properly combined prior to the imposition of the fuel adjustment clause.

Extensions of the Basic Model

The Length of Time Between Hearings

The model can be readily extended to demonstrate the relationship between the magnitude of the input distortion and the length of time between hearings. If rate reviews take place ever n+2 periods, then there are n periods between hearings when the rate of return constraint is not binding and price is governed only by the automatic fuel adjustment clause. Furthermore, if the price of output in periods beyond the next rate review is independent of behavior prior to the rate review and all inputs are variable, then the firm's profit maximization problem can be reduced to one of maximizing profits in each set of n+1 periods.

The relevant Lagrangian function for each independent set of n+1 periods is

$$f = \sum_{t=1}^{n+1} b_t P_t Q_t - \sum_{t=1}^{n+1} b_t (w_t L_t + f_t F_t + r_t K_t) - \lambda_1 (P_1 -$$

$$(w_1 L_1 + f_1 F_1 + sK_1)/Q_1) - \sum_{t=2}^{n+1} \lambda_t (P_t - P_1 - \phi (f_t F_t / Q_t$$

$$- f_1 F_1 / Q_1)). \qquad 3.52$$

Here b_t is the discount factor for period t, so b_1 is equal to one and $b_t < 1$ for $t > 1$. The value of λ_t is the increase in profits which would result from a one unit relaxation of

period t's price constraint. Again, differentiating with respect to each input, the following first order conditions for period one (the review period) are found:

$$\partial \pounds/\partial L_1 = Q_1 \cdot \partial P_1/\partial Q_1 \cdot \partial Q_1/\partial L_1 + P_1 \cdot \partial Q_1/\partial L_1 - w_1$$
$$- \lambda_1(\partial P_1/\partial Q_1 \cdot \partial Q_1/\partial L_1 + (w_1L_1 + f_1P_1 + sK_1)/Q_1^2 \cdot \partial Q_1/\partial L_1$$
$$- w_1/Q_1) - \sum_{t=2}^{n+1} \lambda_t(\partial P_1/\partial Q_1 \cdot \partial Q_1/\partial L_1 - \phi f_1P_1/Q_1^2 \cdot \partial Q_1/\partial L_1) \qquad 3.53$$

$$\partial \pounds/\partial K_1 = Q_1 \cdot \partial P_1/\partial Q_1 \cdot \partial Q_1/\partial K_1 + P_1 \cdot \partial Q_1/\partial K_1 - r_1$$
$$- \lambda_1(\partial P_1/\partial Q_1 \cdot \partial Q_1/\partial K_1 + (w_1L_1 + f_1F_1 + sK_1)/Q_1^2 \cdot \partial Q_1/\partial K_1$$
$$- s/Q_1) - \sum_{t=2}^{n+1} \lambda_t(\partial P_1/\partial Q_1 \cdot \partial Q_1/\partial K_1 - \phi f_1F_1/Q_1^2 \cdot \partial Q_1/\partial K_1) \qquad 3.54$$

$$\partial \pounds/\partial F_1 = Q_1 \cdot \partial P_1/\partial Q_1 \cdot \partial Q_1/\partial F_1 + P_1 \cdot \partial Q_1/\partial F_1 - f_1$$
$$- \lambda_1(\partial P_1/\partial Q_1 \cdot \partial Q_1/\partial F_1 + (w_1L_1 + f_1F_1 + sK_1)/Q_1^2 \cdot \partial Q_1/\partial F_1$$
$$- f_1/Q_1) - \sum_{t=2}^{n+1} \lambda_t(\partial P_1/\partial Q_1 \cdot \partial Q_1/\partial F_1 - \phi f_1F_1/Q_1^2 \cdot \partial Q_1/\partial F_1$$
$$+ \phi f_1/Q_1) \qquad 3.55$$

Now the ratio of marginal products can be compared to the factor price ratio for each pair of inputs at the point of profit maximization.

$$MPL_1/MPK_1 = w_1(1 - \lambda_1/Q_1)/r_1(1 - \lambda_1/Q_1 \quad s/r_1) \qquad 3.56$$

$$MPL_1/MPF_1 = w_1(1 - \lambda_1/Q_1)/f_1(1 - \lambda_1/Q_1 + \sum_{t=2}^{n+1} \lambda_t\phi/Q_1) \qquad 3.57$$

$$MPK_1/MPF_1 = r_1(1 - \lambda_1/Q_1 \cdot s/r)/f_1(1 - \lambda_1 Q_1 + \sum_{t=2}^{n+1} \lambda_t\phi/Q_1) \qquad 3.58$$

The results are intuitively appealing. Since the utility's benefit from a base period distortion against fuel now extends beyond period two, a greater input bias away from fuel in period one would be expected. And this is in fact what is revealed. If the regulated price is below the profit maximizing price in all periods then $\lambda_t > 0$ for all t, and

$$\sum_{t=2}^{n+1} \lambda_t\phi/Q_1 > \lambda_2\phi/Q_1. \qquad 3.59$$

A comparison of equation 3.57 and 3.58 with equations 3.48 and 3.49 indicates that the magnitudes of the capital-fuel and labor-fuel distortions in period one are strictly increasing functions of n, the number of periods between rate reviews. The labor-capital ratio for the base period is unaffected by a change in the number of periods between reviews.

Input ratios for the nonreview periods are unaffected by an increase in the number of periods between hearings. Inputs will be combined in a manner which will satisfy the following equations, for $1 < t < n + 2$.

$$MPL_t/MPK_t = w_t/r_t \qquad 3.60$$

$$MPL_t/MPF_t = w_t/f_t(1 - \lambda_t\phi/b_tQ_t) \qquad 3.61$$

$$MPK_t/MPF_t = r_t/f_t(1 - \lambda_t\phi/b_tQ_t). \qquad 3.62$$

Equations 3.60 through 3.62 are a simple generalization of equation 3.24 through 3.26 for the case of multiple periods between hearings.

A Lag in the Pass-Through of Fuel Cost Increases

Many states require that utilities wait more than a single period before being permitted to increase prices in response to fuel cost increases. Suppose that a firm must wait γ periods before passing on a fuel cost increase and a rate review takes place every n+2 periods. If the price of output beyond the next rate review is independent of the firm's behavior prior to that review and all inputs are readily variable, then the firm's profit maximization problem can again be reduced to one of maximizing profits in each set of n+1 periods. Letting one denote the period of the rate review, the relevant price constraints are

$$P_1 \leq (w_1L_1 + f_1F_1 + sK_1)/Q_1 \quad \text{for } t = 1 \qquad 3.63$$

$$P_t \leq P_1 \quad \text{for } 1 \leq t \leq \gamma \qquad 3.64$$

$$P_t \leq P_1 + \phi(f_{t-\gamma}F_{t-\gamma}/Q_{t-\gamma} - f_1F_1/Q_1)$$
$$\text{for } \gamma+1 \leq t \leq n+1 \qquad 3.65$$

The relevant Lagrangian function for such a firm is

$$\pounds = \sum_{t=1}^{n+1} b_tP_tQ_t - \sum_{t=1}^{n+1} b_t(w_tL_t + f_tF_t + r_tK_t) -$$

$$\lambda_1(P_1 - (w_1L_1 + f_1P_1 + sK_1)/Q_1) - \sum_{t=2}^{\gamma} \lambda_t(P_t - P_1) -$$

$$\sum_{t=\gamma+1}^{n+1} \lambda_t(P_t - P_1 - \phi(f_{t-\gamma}F_{t-\gamma}/Q_{t-\gamma} - f_1F_1/Q_1)). \qquad 3.66$$

And differentiating with respect to each input for the first period yields the following equations:

$$\partial\pounds/\partial L_1 = Q_1 \cdot \partial P_1/\partial Q_1 \cdot \partial Q_1/\partial L_1 + P_1 \cdot \partial Q_1/\partial L_1 - w_1$$

$$- \lambda_1(\partial P_1/\partial Q_1 \cdot \partial Q_1/\partial L_1 + (w_1L_1 + f_1F_1 + sK_1)\, Q_1^2 \cdot \partial Q_1 \partial L_1$$

$$- w_1/Q_1) - \sum_{t=2}^{\gamma} \lambda_t(- \partial P_1/\partial Q_1 \cdot \partial Q_1/\partial L_1) - \sum_{t=\gamma+1}^{n+1} \lambda_t(- \partial P_1/\partial Q_1$$

$$\cdot \partial Q_1/\partial L_1 - \phi f_1F_1/Q_1^2 \cdot \partial Q_1/\partial L_1) \qquad 3.67$$

$$\partial \pounds/\partial K_1 = Q_1 \cdot \partial P_1/\partial Q_1 \cdot \partial Q_1/\partial K_1 + P_1 \cdot \partial Q_1/\partial K_1 - r_1$$
$$- \lambda_1(\partial P_1/\partial Q_1 \cdot \partial Q_1/\partial K_1 + (w_1L_1 + f_1F_1 + sK_1)/Q_1^2 \cdot \partial Q_1/\partial K_1$$
$$- s/Q_1) - \sum_{t=2}^{\gamma} \lambda_t(- \partial P_1/\partial Q_1 \cdot \partial Q_1/\partial K_1) - \sum_{t=\gamma+1}^{n+1} \lambda_t(- \partial P_1/\partial Q_1$$
$$\cdot \partial Q_1/\partial K_1 - \phi f_1F_1/Q_1^2 \cdot \partial Q_1/\partial K_1) \qquad 3.68$$

$$\partial \pounds/\partial F_1 = Q_1 \cdot \partial P_1/\partial Q_1 \cdot \partial Q_1/\partial F_1 + P_1 \cdot \partial Q_1/\partial F_1 - f_1$$
$$- \lambda_1(\partial P_1/\partial Q_1 \cdot \partial Q_1/\partial F_1) + (w_1L_1 + f_1F_1 + sK_1)/Q_1^2 \cdot \partial Q_1/\partial F_1$$
$$- f_1/Q_1) - \sum_{t=2}^{\gamma} \lambda_t(- \partial P_1/\partial Q_1 \cdot \partial Q_1/\partial F_1) - \sum_{t=\gamma+1}^{n+1} \lambda_t(- \partial P_1/\partial Q_1$$
$$\cdot \partial Q_1/\partial F_1 - \phi f_1F_1/Q_1^2 \cdot \partial Q_1/\partial F_1 + \phi f_1/Q_1) \qquad 3.69$$

The first period's discount factor, b_1, is equal to one and for this reason does not appear in the above equations.

Setting equation 3.67 through 3.69 equal to zero, the ratios of the marginal products can be constructed for each factor pair at the point of profit maximization.

$$MPL_1/MPK_1 = w_1(1 - \lambda_1/Q_1/r_1(1 - \lambda_1/Q_1 \cdot s/r_1) \qquad 3.70$$

$$MPL_1/MPF_1 = w_1(1 - \lambda_1/Q_1)/f_1(1 - \lambda_1/Q_1 + \sum_{t=\gamma+1}^{n+1} \lambda_t\phi f_1/Q_1)$$

3.71

$$MPK_1/MPF_1 = r_1(1 - \lambda_1/Q_1 \cdot s/r_1)/f_1(1 - \lambda_1/Q_1 + \sum_{t=\gamma+1}^{n+1} \lambda_t \phi f_1/Q_1) \quad 3.72$$

Finally, a comparison of equations 3.70 through 3.72 to equations 3.57 through 3.59 reveals the impact on factor utilization of the introduction of a lag in the pass through of fuel cost increases.

Again the results are intuitively appealing. The output price established in the review period now remains in affect for γ periods. This effectively diminishes any gain associated with a base period distortion against fuel. An increase in the employment of fuel relative to labor would thus be expected for the base period. A comparison of equation 3.71 to equation 3.57 demonstrates that fuel usage should, in fact, increase relative to labor usage in the first period. Similarly, a comparison of equation 3.72 to equation 3.58 indicates that the marginal product of fuel will fall relative to the marginal product of capital in the base period or that fuel usage will increase relative to capital for a given output.

The next step is to examine the impact of the imposition of a pass-through lag on factor utilization for nonreview periods. The same analysis can be repeated but all interim periods will no longer be affected in the same manner. The periods such that $t > 1$ and $t+\gamma \leq n+1$ will be examined next. Equation 3.63 must again be differentiated

with respect to each of period t's inputs for the periods of interest.

$$\partial \pounds/\partial L_t = b_t Q_t \cdot \partial P_t/\partial Q_t \cdot \partial Q_t/\partial L_t + b_t P_t \cdot \partial Q_t/\partial L_t$$
$$- b_t w_t - \lambda_t \cdot \partial P_t/\partial Q_t \cdot \partial Q_t/\partial L_t - \lambda_{t+\gamma} \cdot \phi f_t P_t/Q_t^2 \cdot \partial Q_t/\partial L_t \tag{3.73}$$

$$\partial \pounds/\partial K_t = b_t Q_t \cdot \partial P_t/\partial Q_t \cdot \partial Q_t/\partial K_t + b_t P_t \cdot \partial Q_t/\partial K_t$$
$$- b_t r_t - \lambda_t \cdot \partial P_t/\partial Q_t \cdot \partial Q_t/\partial K_t - \lambda_{t+\gamma} \cdot \phi f_t P_t/Q_t^2 \cdot \partial Q_t/\partial K_t \tag{3.74}$$

$$\partial \pounds/\partial F_t = b_t Q_t \cdot \partial P_t/\partial Q_t \cdot \partial Q_t/\partial F_t + b_t P_t \cdot \partial Q_t/\partial F_t$$
$$- b_t f_t - \lambda_t \cdot \partial P_t/\partial Q_t \cdot \partial Q_t/\partial F_t - \lambda_{t+\gamma} \cdot \phi f_t P_t/Q_t^2 \cdot \partial Q_t/\partial F_t$$
$$- \lambda_{t+\gamma} \cdot \phi f_t/Q_t \tag{3.75}$$

Profit maximization requires that the above functions be equal to zero. Setting them equal to zero, the profit maximizing marginal product ratios for the various factor pairs can again be constructed. Again, these ratios are for the periods between reviews such that $t > 1$ and $t+\gamma \leq n+1$.

$$MPL_t/MPK_t = w_t/r_t \tag{3.76}$$

$$MPL_t/MPF_t = w_t/f_t(1 - \lambda_{t+\gamma} \cdot \phi/b_t Q_t) \tag{3.77}$$

$$MPK_t/MPF_t = r_t/f_t(1 - \lambda_{t+\gamma} \cdot \phi/b_t Q_t) \tag{3.78}$$

Equation 3.76 demonstrates that labor and capital will be optimally combined in these periods as they were prior to the introduction of the pass-through lag. The impact of the pass-through lag on the firm's labor to fuel and capital to fuel ratios is not immediately evident. A comparison of equations 3.77 and 3.78 to equations 3.61 and 3.62 indicates that fuel will be combined more efficiently with the other factors if and only if $\lambda_{t+\gamma}$ is less than λ_t, assuming again that $\lambda_t > 0$ for all t. If the firm's cost and demand functions are stable across time and output is constant, then $\lambda_{t+\gamma} < \lambda_t$ as $\partial\lambda_t/\partial b_t > 0$ for all t and the discount factor, b_t, is a decreasing function of time. In a dynamic economy where the cost and demand functions vary, however, little can be said about the impact of the pass-through lag on allocative efficiency in these periods.

It has been argued many times that a pass-through lag will unambiguously improve efficiency and, for this reason, the possibility of a contrary result deserves further elaboration. The confusion again centers on a failure to recognize that the fuel adjustment constraint is merely a price constraint and not a revenue constraint. There is more involved than the timing of the receipt of a fixed quantity of money.

Consider, for example, the case of a utility operating in a northern region and subject to this form of regulation. It can be argued that an immediate fuel adjustment increase may cause less input distortion in the month of October

than a fuel adjustment clause characterized by a three month lag. The reason should be apparent. Demand for electricity tends to be greater and less elastic during winter months. It is thus quite reasonable that the firm stands more to gain from a given price increase in January than in October. The greater increment to profit may more than compensate for the delay in receipt of the funds.

Finally, the impact of a pass-through lag on those periods such that $t+\gamma > n+1$ must be considered. As modeled, those periods beyond $t=n+1$ are independent of the periods prior to $n+1$. A rate review is held at time $n+2$ and the price is set to conform again to a rate of return constraint. The new price then becomes the base price until the next rate review. In essence, this means that fuel cost increases incurred in those periods such that $t+\gamma > n+1$ will never directly determine output price. The firm has no incentive to distort the input mix in these periods in favor of the fuel input. All inputs should thus be properly combined.

The Inclusion of Only Some Components of the Fuel Expense

The components of the fuel expense which are covered by the automatic fuel adjustment clause vary from state to state and, in some cases, from company to company within a single state. This analysis can be immediately extended to exclude certain components of the fuel expense from being

passed on to consumers via the automatic adjustment clause or to include nonfuel components. This is a primary advantage of working with a three factor model including a neutral factor. Labor is neutral in the sense that the output price is not directly constrained by the quantity of labor employed. Fuel components not covered by the automatic adjustment clause will be combined with covered components and capital in the same proportions in which labor is combined with fuel and capital in the previous analysis. Similarly, nonfuel expenses covered by the adjustment clause will be combined with capital and noncovered expenses in the same proportions that fuel is combined with capital and labor in the preceding analysis.

Capital as a Fixed Factor

The preceding analysis assumes that the firm can readily adjust its input quantities. This is, in the case of the electric utility industry, an exceedingly unrealistic assumption with respect to the capital input. This section will incorporate capital into the model as a fixed factor by requiring that the firm retain the same capital stock for a periods. Alpha can be interpreted as the number of periods required to build or add on to an existing plant. Labor and fuel will continue to be treated as readily variable inputs.

The behavior of the unregulated firm must first be analyzed as this behavior will again serve as the standard

for comparison. Each set of a periods is independent for the firm as all inputs can be completely altered beyond this time frame. Thus the analysis can focus on a single set of a periods. The relevant Lagrangian function is

$$\pounds = \sum_{t=1}^{a} b_t P_t Q_t - \sum_{t=1}^{a} b_t (w_t L_t + f_t F_t + r_t \bar{K}) \qquad 3.79$$

where $\bar{K}$ represents the fixed capital stock chosen in period one.

Again the Lagrangian function can be differentiated with respect to each of the choice variables, the derivatives set equal to zero and the cost minimizing input combinations constructed. Differentiation with respect to labor and fuel for period t yields the following equations.

$$\partial\pounds/\partial L_t = b_t Q_t \cdot \partial P_t/\partial Q_t \cdot \partial Q_t/\partial L_t + b_t P_t \cdot \partial Q_t/\partial L_t - b_t w_t \qquad 3.80$$

$$\partial\pounds/\partial F_t = b_t Q_t \cdot \partial P_t/\partial Q_t \cdot \partial Q_t/\partial F_t + b_t P_t \cdot \partial Q_t/\partial F_t - b_t f_t \qquad 3.81$$

Setting equations 3.80 and 3.81 equal to zero, the cost minimizing ratio of the marginal products is found to be

$$MPL_t/MPF_t = w_t/f_t \, . \qquad 3.82$$

Equation 3.82 indicates that the socially optimal or efficient combination of labor and fuel has remained unchanged.

Finally, the Lagrangian function must be differentiated with respect to $\bar{K}$, the constant capital input.

$$\partial \mathcal{L}/\partial \bar{K} = \sum_{t=1}^{\infty} (b_t Q_t \cdot \partial P_t/\partial Q_t \cdot \partial Q_t/\partial \bar{K} + b_t P_t \cdot \partial Q_t/\partial \bar{K})$$

$$- \sum_{t=1}^{\infty} b_t r_t \qquad 3.83$$

Equation 3.83 can be set equal to zero and rewritten in the following manner:

$$\sum_{t=1}^{\infty} (b_t Q_t \cdot \partial P_t/\partial Q_t \cdot \partial Q_t/\partial \bar{K} + b_t P_t \cdot \partial Q_t/\partial \bar{K})$$

$$= \sum_{t=1}^{\infty} b_t r_t \ . \qquad 3.84$$

The left side of equation 3.84 is simply the discounted value of the marginal revenue products. Equation 3.81 indicates that the firm with a fixed capital input will maximize profits by equating the discounted marginal revenue products to the discounted factor prices.

It is now evident that if output, product prices, demand and input prices remain constant, then the optimal combination of capital with the other inputs will be the same as in the case of perfectly variable inputs. That is, the ratio of marginal products will be equal to the input

price ratio for all factor pairs in all periods. But in a dynamic economy there is no reason to believe that optimality involves equality of these ratios. The new profit maximizing marginal product ratios for capital and the other two inputs are

$$MPL_t/MP\bar{K}_t = b_t w_t/(b_t r_t - \sum_{j=1, j\neq t}^{n} \{b_j Q_j \cdot \partial P_j/\partial Q_j \cdot \partial Q_j/\partial \bar{K} + b_j P_j \cdot \partial Q_j/\partial \bar{K} - b_j r_j\}) \qquad 3.85$$

$$MPF_t/MP\bar{K}_t = b_t f_t/(b_t r_t - \sum_{j=1, j\neq t}^{n} \{b_j Q_j \cdot \partial P_j/\partial Q_j \cdot \partial Q_j/\partial \bar{K} + b_j P_j \cdot \partial Q_j/\partial \bar{K} - b_j r_j\}) \qquad 3.86$$

Equations 3.85 and 3.86 can be considerably simplified by defining a new variable

$$MRP\bar{K}_t = \partial P_t Q_t/\partial \bar{K} \qquad 3.87$$

$MRP\bar{K}_t$ is simply the marginal revenue product of the fixed factor in period t. With the appropriate substitutions, the two equations can be rewritten

$$MPL_t/MP\bar{K}_t = b_t w_t/(b_t r_t - \sum_{j=1, j\neq t}^{n} b_j (MRP\bar{K}_j - r_j)) \qquad 3.88$$

$$MP\bar{K}_t/MPF_t = (b_t r_t - \sum_{j=1, j\neq t}^{n} b_j (MRP\bar{K}_j - r_j))/b_t f_t \qquad 3.89$$

where j is also a time subscript. The time paths of $MRP\bar{K}$ and the price of capital will determine in which periods capital appears to be overutilized or underutilized relative to the perfect variability conditions. But it is quite clear that it will now make little sense to attribute all deviation from the perfect variability optimality conditions to regulation. In fact, deviation from these conditions can no longer be interpreted as inefficiency.

The Firm Subject Only to an Automatic Fuel Adjustment Clause

The automatic fuel adjustment clause can again be imposed just as it was in the previous analysis. The firm is faced with the constraint introduced in equation 3.12. The relevant Lagrangian function becomes

$$\mathcal{L} = \sum_{t=1}^{\alpha} b_t P_t Q_t - \sum_{t=1}^{\alpha} b_t (w_t L_t + f_t F_t + r_t \bar{K}) - \sum_{t=2}^{\alpha} \lambda_t (P_t - P_1 - \phi(f_t F_t / Q_t - f_1 F_1 / Q_1)) \qquad 3.90$$

Again, the Lagrangian function can be differentiated with respect to each input. Differentiating with respect to L_1 and F_1 yields a generalized version of equations 3.15 and 3.16.

$$\partial\mathcal{L}/\partial L_1 = Q_1 \cdot \partial P_1/\partial Q_1 \cdot \partial Q_1/\partial L_1 + P_1 \cdot \partial Q_1/\partial L_1 - w_1 - \sum_{t=2}^{\alpha} \lambda_t (- \partial P_1/\partial Q_1 \cdot \partial Q_1/\partial L_1 - \phi f_1 F_1/Q_1^2 \cdot \partial Q_1/\partial L_1) \qquad 3.91$$

$$\partial \pounds/\partial F_1 = Q_1 \cdot \partial P_1/\partial Q_1 \cdot \partial Q_1/\partial F_1 + P_1 \cdot \partial Q_1/\partial F_1 - f_1$$
$$- \sum_{t=2}^{a} \lambda_t(- \partial P_1/\partial Q_1 \cdot \partial Q_1/\partial F_1 - \phi f_1 F_1/Q_1^2 \cdot \partial Q_1/\partial F_1$$
$$+ \phi f_1/Q_1) \qquad 3.92$$

The Lagrangian function must also be differentiated with respect to $\bar{K}$.

$$\partial \pounds/\partial \bar{K} = \sum_{t=1}^{a} (b_t Q_t \cdot \partial P_t/\partial Q_t \cdot \partial Q_t/\partial \bar{K} + b_t P_t \cdot \partial Q_t/\partial \bar{K})$$
$$- \sum_{t=1}^{a} b_t r_t - \sum_{t=2}^{a} \lambda_t(\partial P_t/\partial Q_t \cdot \partial Q_t/\partial \bar{K} - \partial P_1/\partial Q_1 \cdot \partial Q_1/\partial \bar{K}$$
$$+ \phi(f_t F_t/Q_t^2 \cdot \partial Q_t/\partial \bar{K} - f_1 F_1/Q_1^2 \cdot \partial Q_1/\partial \bar{K}_1)) \qquad 3.93$$

Setting equation 3.91 through 3.93 equal to zero, the profit maximizing marginal product ratios can be constructed for the first period

$$MPL_1/MP\bar{K}_1 = w_1/(r_1 - \sum_{t=2}^{a} b_t(MRP\bar{K}_t - r_t)$$
$$+ \sum_{t=2}^{a} \lambda_t(\partial P_t/\partial Q_t \cdot \partial Q_t/\partial \bar{K}_t + \phi f_t F_t/Q_t^2 \cdot \partial Q_t/\partial \bar{K})) \qquad 3.94$$

$$MPL_1/MPF_1 = w_1/(f_1 + \sum_{t=2}^{n} \lambda_t \cdot \phi f_1/Q_1) \qquad 3.95$$

$$MP\bar{K}_1/MPF_1 = (r_1 - \sum_{t=2}^{\alpha} b_t(MRP\bar{K}_t - r_t)$$
$$+ \sum_{t=2}^{\alpha} \lambda_t \,(\partial P_t/\partial Q_t \cdot \partial Q_t/\partial \bar{K}_t + \phi f_t F_t/Q_t^2 \cdot \partial Q_t/\partial \bar{K}_t))/(f_1$$
$$+ \sum_{t=2}^{\alpha} \lambda_t \phi f_1/Q_1) \qquad 3.96$$

Equation 3.95 demonstrates that fuel will be underutilized relative to labor in the base period. However, the effect of the automatic fuel adjustment clause on the firm's combination of capital with the variable inputs is no longer clear.

From equation 3.94, it is clear that capital will be overutilized relative to labor if and only if

$$\sum_{t=2}^{\alpha} \lambda_t(\partial P_t/\partial Q_t \cdot \partial Q_t/\partial \bar{K}_t + \phi f_t F_t/Q_t^2 \cdot \partial Q_t/\partial \bar{K}) < 0. \qquad 3.97$$

The condition can be rewritten as

$$\sum_{t=2}^{\alpha} \lambda_t(\partial P_t/\partial Q_t + \phi f_t F_t/Q_t^2)\partial Q_t/\partial \bar{K} < 0. \qquad 3.98$$

Assuming that the regulatory constraint is binding in each period and that the marginal product of capital is positive, the condition simply reduces to

$$\partial P_t/\partial Q_t + \phi f_t F_t/Q_t^2 < 0 \qquad 3.99$$

The first term is clearly negative and is nothing more than the slope of the demand curve. The second term will be positive but the magnitude cannot be determined without knowing the precise form of the production function as well as factor prices and ϕ. Thus no general statement can be made concerning the direction of distortion for this factor pair.

For similar reasons, no generalizations can be made concerning the distortion involving the firm's combination of capital and fuel. From equation 3.96, capital will be overutilized relative to fuel if and only if

$$\sum_{t=2}^{a} \lambda_t \left(\partial P_t/\partial Q_t \cdot \partial Q_t/\partial \bar{K} + \phi f_t P_t/Q_t^{\,2} \cdot \partial Q_t/\partial \bar{K}\right)$$

$$< \sum_{t=2}^{a} \lambda_t \phi f_1/Q_1 \qquad 3.100$$

The condition that

$$\partial P_t/\partial Q_t + \phi f_t P_t/Q_t^{\,2} < 0 \qquad 3.101$$

is sufficient for capital overutilization but is not, in this case, a necessary condition. The source of the ambiguity concerning factor combinations, which was not encountered in the case of perfectly variable inputs, will be further discussed following an examination of firm behavior beyond the base period.

In order to analyze the impact of the automatic fuel adjustment clause beyond the base period, equation 3.90 must be partially differentiated with respect to the variable inputs for a period t where t > 1.

$$\partial f/\partial L_t = b_t Q_t \cdot \partial P_t/\partial Q_t \cdot \partial Q_t/\partial L_t + b_t P_t \cdot \partial Q_t/\partial L_t$$

$$- b_t w_t - \lambda_t(\partial P_t/\partial Q_t \cdot \partial Q_t/\partial L_t + \phi f_t F_t/Q_t^2 \cdot \partial Q_t/\partial L_t) \qquad 3.102$$

$$\partial f/\partial F_t = b_t Q_t \cdot \partial P_t/\partial Q_t \cdot \partial Q_t/\partial F_t + b_t P_t \cdot \partial Q_t/\partial F_t$$

$$- b_t f_t - \lambda_t(\partial P_t/\partial Q_t \cdot \partial Q_t/\partial F_t + \phi f_t F_t/Q_t^2 \cdot \partial Q_t/\partial F_t$$

$$- \phi f_t/Q_t) \qquad 3.103$$

Setting equations 3.102, 3.103 and 3.93 equal to zero and combining, the constrained profit maximizing marginal product ratios can be determined.

$$MPL_t/MPF_t = b_t w_t/(b_t f_t - \lambda_t \phi f_t/Q_t) \qquad 3.104$$

$$MPL_t/MP\bar{K}_t = b_t w_t/(b_t r_t - \sum_{j=1, j\neq t}^{n} (MRP\bar{K}_j - r_j)$$

$$+ \sum_{j=2, j\neq t}^{n} \lambda_j(\partial P_j/\partial Q_j \cdot \partial Q_j/\partial \bar{K} - \partial P_1/\partial Q_1 \cdot \partial Q_1/\partial \bar{K}$$

$$+ \phi(f_j F_j/Q_j^2 \cdot \partial Q_j/\partial \bar{K} - f_1 F_1/Q_1^2 \cdot \partial Q_1/\partial \bar{K}))$$

$$+ \lambda_t(- \partial P_1/\partial Q_1 \cdot \partial Q_1/\partial \bar{K} - \phi f_1 F_1/Q_1^2 \cdot \partial Q_1/\partial \bar{K})) \qquad 3.105$$

$$MP\bar{K}_t/MPF_t = (b_t r_t - \sum_{j=1, j\neq t}^{a} (MRP\bar{K}_j - r_j)$$

$$+ \sum_{j=2, j\neq t}^{a} \lambda_j (\partial P_j/\partial Q_j \cdot \partial Q_j/\partial \bar{K} - \partial P_1/\partial Q_1 \cdot \partial Q_1/\partial \bar{K}$$

$$+ \phi(f_j F_j/Q_j^{\,2} \cdot \partial Q/\partial \bar{K} - f_1 F_1/Q_1^{\,2} \cdot \partial Q_1/\partial \bar{K}))$$

$$+ \lambda_t(- \partial P_1/\partial Q_1 \cdot \partial Q_1/\partial \bar{K} - \phi f_1 F_1/Q_1^{\,2} \cdot \partial Q_1/\partial \bar{K}))/(b_t f_t$$

$$- \lambda_t \phi f_t/Q_t) \qquad 3.106$$

An examination of equation 3.104 reveals that fuel will be overutilized relative to labor in period t for all t greater than one. That is, fuel will be overutilized relative to labor in all periods beyond the base period. Equations 3.105 and 3.106 reveal that again little can be said about the firm's constrained profit maximizing combination of capital with the variable factors.

The uncertainty concerning the combination of inputs when capital is a fixed input is closely related to the uncertainty concerning the output effect associated with the automatic fuel adjustment clause. Returning to equation 3.91, the first order condition for labor for period one can be rewritten as follows.

$$MRPL_1 - w_1 = \sum_{t=2}^{a} \lambda_t (- \partial P_1/\partial Q_1 \cdot \partial Q_1/\partial L_1 - \phi f_1 P_1/Q_1^{\,2}$$

$$\cdot \partial Q_1/\partial L_1) \qquad 3.107$$

Since labor is a neutral factor with respect to regulation, any increase or decrease in its usage will be for the purpose of adjusting output in response to the automatic fuel adjustment clause. If the right hand side of equation 3.107 is positive then an output reduction in period one is consistent with constrained profit maximization and vice versa. The indeterminacy concerning period one's output effect is intuitively plausible. Since the firm faces no regulatory constraint in period one, any change in output will be designed to increase the permissible prices in subsequent periods and thus profits for those periods (again λ_t is assumed to be positive for all periods). The regulated prices in subsequent periods is an increasing function of F_1 and a decreasing function of f_1F_1/Q_1. The firm thus has two options in terms of output adjustment. It can increase F_1 which requires that Q_1 be reduced or it can reduce f_1F_1/Q_1 which requires that Q_1 be increased. Clearly no general statement can be made concerning the output effect in the base period without knowledge of the precise functional forms and factor prices involved.

The utilization of labor beyond the base period can also be examined. Equation 3.102 can be rewritten as follows:

$$MRPL_t = w_t = \lambda_t(\partial P_t/\partial Q_t \cdot \partial Q_t/\partial L_t$$

$$+ \phi f_t F_t/{Q_t}^2 \cdot \partial Q_t/\partial L_t) \qquad 3.108$$

Again, labor will be altered to adjust output in response to the automatic adjustment clause. If the right hand side of equation 3.108 is positive then an output contraction is consistent with profit maximization and vice versa. Again, the sign is uncertain as the first term is negative and the second is clearly positive.

The indeterminacy concerning the output effect was present in the case of perfectly variable inputs as well The indeterminacy did not extend to the combination of inputs, however, as all inputs could be varied in each period and were thus equally affected. Now the firm must choose a single capital level and maintain it throughout so that the entire stream of output effects determines the adjustment in the amount of capital employed as the result of the automatic adjustment clause. If the automatic adjustment clause induces the firm to expand output in every period then for all $t > i$,

$$\lambda_t(\partial F_t/\partial Q_t + \phi f_t F_t/Q_t^2) < 0 \qquad 3.109$$

and

$$(-\partial F_i/\partial Q_i - \phi f_i F_i/Q_i^2) < 0. \qquad 3.110$$

In this case, it is clear from equation 3.105 that

$$MPL_t/MP\bar{K}_t > b_t w_t/(b_t r_t - \sum_{j=1, j\neq t}^{n} (MRPK_j - r_j)). \qquad 3.111$$

That is, capital will be overutilized relative to labor in all periods beyond the base period. It is also apparent from equation 3.94 that

$$MPL_1/MP\bar{K}_1 > w_1/(r_1 - \sum_{t=2}^{N} b_t(MRP\bar{K}_t - r_t). \qquad 3.112$$

Thus, if the output effect is an expansion of output in every period, capital will be overutilized relative to labor in every period. The reverse is also true as it simply involves a reversing of the inequalities in equation 3.109 through 3.112. That is, if the output effect is a reduction of output in every period then capital will be underutilized relative to labor in every period. Examining equations 3.111 and 3.112 it is apparent that in a relatively stable market, one would expect that the output effect for period one would be of the opposite direction of the other periods. In the most likely case that the output effect is an expansion in some periods and a reduction in others, no generalizations can be made concerning the combination of capital with the variable inputs.

The above analysis again demonstrates the importance of selecting the proper criterion against which to evaluate the impact of regulatory policy on firm performance. Suppose that the firm's performance is evaluated according to the efficiency criteria corresponding to the case of perfectly variable inputs. A firm's combination of capital

and labor would be judged optimal or efficient if the following condition were satisfied.

$$MPL_t/MPK_t = w_t/r_t. \tag{3.116}$$

But if the firm's capital input is actually fixed, then the firm will maximize profits by combining labor and capital according to equation 3.88 in the absence of regulation and according to equation 3.105 in the presence of an automatic fuel adjustment clause. Now if the industry is stable so that the output effects all have the same sign, then equation 3.105 will be closer to equation 3.116 than to equation 3.88. The inefficiency associated with the automatic fuel adjustment clause would thus be considerably understated by viewing capital as a variable input.

Because of the uncertainty concerning the impact of the automatic fuel adjustment clause on the firm's combination of capital with the variable inputs there is little value in introducing a rate of return constraint. Rate of return regulation introduces distortion only into the combining of the fixed factor with the variable factors. The fuel to labor ratio derived above would remain unchanged. And, of course, it would not be possible to ascertain whether the distortions in the other factor pairs would be offset or reinforced as no generalizations can be made concerning the direction of these distortions.

It is the uncertainty concerning the impact of the automatic fuel adjustment clause on output, both in the case of variable inputs as well as in the case of a fixed factor, which prevents any general statements on absolute price efficiency. It is clear that the fuel adjustment clause induces relative price inefficiency thus precluding the possibility of cost minimization and economic efficiency but beyond this little can be said. It is not clear in what direction the fuel adjustment clause affects the firm's output. The impact of the fuel adjustment clause on technical efficiency will be examined further.

Technical Efficiency

A firm is said to be technically inefficient if it fails to maximize the output obtained from its chosen input bundle, subject to its production function. It can be argued that, in the simple model with variable inputs, the automatic fuel adjustment clause may, under some circumstances, actually induce the firm to waste inputs or to behave in a technically inefficient manner.

The model can be extended to focus on this possibility. Let X_{F1}, X_{L1} and X_{K1} represent the quantities of fuel, labor and capital, respectively, which are wasted in period 1. Because they are wasted, output and thus price are not affected by these variables. The modified Lagrangian function for the two period case becomes:

$$\pounds = P_1Q_1 - (w_1L_1 + f_1F_1 + r_1K_1) - (w_1X_{L1} + f_1X_{F1} + r_1X_{K1})$$
$$+ b_2P_2Q_2 - b_2(w_2L_2 + f_2F_2 + r_2K_2) - b_2(w_2X_{L2} + f_2X_{F2}$$
$$+ r_2X_{K2}) - \lambda_2\{P_2 - P_1 - \phi(f_2(F_2 + X_{F2})/Q_2 - f_1(F_1 + X_{F1})/Q_1)\}. \qquad 3.117$$

Differentiation with respect to the waste variables in each period yields the following equations:

$$\partial\pounds/\partial X_{L1} = -w_1 \qquad 3.118$$

$$\partial\pounds/\partial X_{K1} = -r_1 \qquad 3.119$$

$$\partial\pounds/\partial X_{L2} = -w_2 \qquad 3.120$$

$$\partial\pounds/\partial X_{K2} = -r_2 \qquad 3.121$$

$$\partial\pounds/\partial X_{F1} = -f_1 - \lambda_2(\phi f_1/Q_1) \qquad 3.122$$

$$\partial\pounds/\partial X_{F2} = f_2(\lambda_2/Q_2 - \phi b_2) = -b_2f_2 + \lambda_2(\phi f_2/Q_2). \qquad 3.123$$

Equations 3.118 through 3.121 are all clearly negative indicating that the firm has no incentive to waste labor or capital in either period. Equation 3.122 is also clearly negative indicating that the firm has no incentive to waste fuel in the base period. This result is intuitively obvious. The firm attempts to reduce fuel expense per unit of output in period one in response to the fuel adjustment clause as

$\partial P_2/\partial(F_1/Q_1)$ is positive. Unfortunately, it is not clear, a priori, that equstion 3.123 is negative for all values of Q_2, ϕ and b_2. Again, the possibility of fuel wastage in period two is intuitively plausible. By purchasing and disposing of a unit of fuel, the firm incurs a cost of $b_2 f_2$. It also increases its fuel expense per unit of output by f_2/Q_2. It can then increase its period two price by $\phi f_2/Q_2$. Since the value of a price increase is λ_2, the full value of a unit of fuel wastage is $\lambda_2 \phi f_2/Q_2$. Eventually as fuel wastage is increased and price increases, λ_2/Q_2 would fall so that an interior solution is feasible for period two with fuel wastage.

Qualifications

With any simple model there are abstractions from realism. It is hoped that they do not seriously affect the model's explanatory power so that the gains from simplicity more than offset the costs. Some of the shortcomings of the previous analysis are immediately evident and common to many models. First, uncertainty is in no way incorporated. Factor prices, demand functions and productions are all assumed to be known for all periods. It is not clear to what extent uncertainty would affect the conclusions but the analysis would be somewhat more complicated. With the introduction of uncertainty, the cost of capital must be dependent on the amount of profit risk or uncertainty. To the extent that the automatic fuel

adjustment clause reduces profit variance, it would affect the cost of capital causing further adjustment in inputs. Rate of return regulation and the automatic fuel adjustment clause are now much more interrelated.

Another common and somewhat unrealistic assumption concerns the objective of the firm. The goal of the firm is assumed to be the strict maximization of the discounted present value of profits. It is suspected that the relaxation of this assumption, particularly in the presence of uncertainty would have serious repercussions in terms of technical efficiency. This might be the case if the fuel adjustment clause reduces risk. The manager would be free to pursue objectives other than profit maximization with a reduced cost of resource misallocation and a smaller chance of bankruptcy.

The most serious shortcoming, however, has yet to be mentioned. That is the assumption of regulation by formula. As modeled, the regulatory agency sets out the rules of the game before hand and strictly abides by them throughout. Relaxation of this assumption would undoubtedly affect the conclusions while enhancing realism. Even a firm subject to an automatic fuel adjustment clause must, for example, account for its fuel expenses. It is extremely doubtful that the regulatory authority would overlook the intentional wasting of fuel discussed in part six. In fact, proper regulatory response could undoubtedly reduce, if not

eliminate, all of the inefficiency associated with the fuel adjustment clause while maintaining the associated benefits.

Notes

1. These conditions are clearly necessary but not sufficient. The existence of an interior solution is not guaranteed, but the firm which continues finite operate under regulation will combine inputs as indicated, given the assumptions in equation 3.1. The same is true throughout the analysis.

2. Averch and Johnson demonstrate that, under their formulation, if $s \neq r$ then $\lambda_1 < 1$ [12]. Under the current formulation, their constraint is divided through Q_1. Thus λ_1/Q_1 in this paper must also be less than one

CHAPTER FOUR

EMPIRICAL ANALYSIS

Introduction

The purpose of this chapter is to measure and compare efficiency for firms characterized by automatic fuel adjustment mechanisms with those firms not subject to this form of regulation. To render the problem more manageable, only production efficiency for fossil-fuel powered steam generation will be considered. Efficiency in transmission, distribution, accounting or general administration is of little interest to this study as these functions do not involve the fuel input and hence should be unaffected by the presence of an automatic fuel adjustment mechanism.

Issues involving purchased power are also being excluded, although it can be argued that the presence of a fuel adjustment clause may affect the decision to produce power as an alternative to purchasing it. This would affect total cost and hence cost efficiency for the firm. It is plausible, for example, that the firm with a fuel adjustment clause which does not include purchased power in the fuel expense will produce power which could have been purchased at a lower cost. The problem with including such issues in this analysis is that firms would have to be

further subgrouped according to whether the automatic fuel adjustment clause includes a provision for the pass-through of purchased power costs. And, unfortunately, sample sizes are already very small. At any rate, efficiency issues involving purchased power are being deferred to a later study.

It must also be noted that this study focuses only on production efficiency for steam generated electricity where the power source is fossil fuel. Specifically excluded are nuclear and hydraulic generation. Such treatment can be justified in that the possibility for switching between fossil-fuel generation and one of the alternatives is severely limited, especially in the case of hydraulic. Also, one would expect the production functions and thus the cost functions to differ dramatically for these power sources. Finally, inclusion of these costs would again require that firms be sub-grouped according to whether nuclear fuel could be included in the fuel expense under the fuel adjustment clause in effect.

Methodology

Any meaningful evaluation of firm or industry behavior requires a comparison of actual performance with an absolute standard, namely potential performance. It is contrary to theory and intuitively unreasonable to base a measure of efficiency on average relationships. For this reason, a

cost frontier will be estimated for each group of firms and efficiency will be measured relative to those frontiers.

The first problem is one of specifying optimal performance or of defining the frontier against which to evaluate actual performance. In theory, when inputs are not completely variable in each period, the entire time paths of output and input prices must be considered in evaluating efficiency. In practice such a study could take a lifetime.

This analysis will look at two types of frontiers. First, frontiers will be estimated assuming that all inputs are perfectly variable. Optimal behavior will be defined relative to only the current period's output and input prices. Any failure to immediately adjust inputs in response to current conditions will be viewed as inefficiency. Next, the frontiers will be re-estimated recognizing that capital is indeed a fixed input and that other inputs may not be completely variable in relative proportions. It will then be argued that the second approach is, in fact, more reasonable.

Perfectly Variable Inputs

Initially, efficiency will be measured relative to the cost frontier imposed upon the firm by current input prices and the quantity of output produced. The treatment of output as externally controlled is quite reasonable in a regulated industry, such as the electric utility industry, where firms are required to satisfy demand at a regulated

price. The treatment of factor prices as exogenous should pose no serious problems either. If firms have some control over prices, however, then efficiency may be overstated. Fortunately, although Kaserman and Tepel argue that firms subject to automatic fuel adjustment clauses might pay a higher price for the fuel input by consciously engaging in less search, they found no empirical support for this hypothesis [20]. So called "search inefficiency" cannot be incorporated into this methodology.

This analysis will follow the procedure developed by Aigner, Lovell and Schmidt [22]. Their approach assumes a Cobb-Douglas functional form. Although it might be possible to incorporate a different functional form, there is now significant empirical support for the Cobb-Douglas specification, in spite of its restrictive properties [23]. The cost function which will be initially employed can be expressed in log form as follows:

$$\ln C = A + a_1 \ln Q + a_2 \ln P_L + a_3 \ln P_F + a_4 \ln P_K + \varepsilon \qquad 4.1$$

where

C is actual total cost of production

A is a constant

Q is quantity of output produced

P_L is the per unit price of labor

P_F is the per unit price of fuel

P_K is the cost of capital

ϵ is a residual term

α is the vector of coefficients to be estimated.

The point of departure in estimating a stochastic frontier cost function is the decomposition of the error term into two separate components:

$$\epsilon = u + v \tag{4.2}$$

The variable u is a one-sided nonnegative error, it is the absolute value of a variable which is distributed normal $(0, \sigma_u^2)$. The variable v is a two-sided stochastic disturbance distributed normal $(0, \sigma_v^2)$. The variables u and v are assumed to be independently distributed. There is no theoretical justification for the assumption that u is half-normal. However, this procedure requires that the distribution of u be specified and little work has been done on the issue of selecting the distributional form.

The logic behind the specification is that the production process is subject to two distinguishable random disturbances with different characteristics. The nonnegative disturbance u_i reflects the fact that each firm's cost must lie on or above its cost frontier. The variable u_i is the result of factors under the firm's control and can thus be interpreted as inefficiency. But the frontier itself varies between firms and across time for the same firm. The two-sided residual component can thus be

interpreted as luck or events external to the firm. This component also captures errors in observing or measuring the dependent variable.

Aigner, Lovell and Schmidt derive a log likelihood function which can be estimated using maximum likelihood procedures [22]. The likelihood function presented in their paper is for a production frontier, but it can be easily modified to estimate a cost frontier. The relevant log-likelihood function is

$$\ln L(y|\beta,\lambda,\sigma^2) = N\ln(\sqrt{2}/\sqrt{\pi}) + N\ln\sigma^{-1} + \sum_{i=1}^{N} \ln\{1 - F(-\varepsilon_i\lambda\sigma^{-1})\} - 1/2\sigma^2 \cdot \sum_{i=1}^{N} \varepsilon_i^2 \qquad 4.3$$

where

N is the number of observations

y represents the dependent varisble

x represents the vector of independent variables

β represents the vector of coefficients

F represents the cumulative distribution function of the N(0,1) distribution evaluated at $-\varepsilon_i\lambda\sigma^{-1}$

$\sigma^2 = \sigma_u^{\,2} + \sigma_v^{\,2}$

$\lambda = \sigma_u/\sigma_v$

ε is as previously defined.

The only difference between the log likelihood function for the production frontier and the above function is that, in the case of the production frontier, the cumulative

distribution function, F, is evaluated at $\varepsilon_1\lambda\sigma^{-1}$. Thus the first and second derivatives appearing in the Aigner, Lovell and Schmidt paper can be easily adapted to a cost frontier [22]. All that is required is a sign change when evaluating the density functions or cumulative distribution functions appearing therein.

The Newton-Rapheon iterative procedure is employed in calculating the estimates reported herein [24]. The procedure is terminated when the absolute value of the largest change in a parameter is less than or equal to .001 when compared to the values of the previous iteration. The likelihood function appears to be generally well behaved and converges quickly if at all.

Consistent estimates for all of the parameters of the likelihood function can be obtained by regressing the dependent variable on the vector of explanatory variables using ordinary least squares. Estimates for σ_u^2 and σ_v^2 can be obtained from the moments of the ordinary least squares residuals by simultaneously solving the following two equations:

$$\mu_2 = \sigma_v^2 + \left(\frac{\pi-2}{\pi}\right)\sigma_u^2 \qquad 4.4$$

$$\mu_3 = \sqrt{\frac{2}{\pi}}\left(\frac{4-\pi}{\pi}\right)\sigma_u^3 \qquad 4.5$$

where μ_2 and μ_3 are the second and third moments of the residuals respectively. The estimate of λ is then simply

the ratio of σ_u to σ_v. And the estimated value for σ^2 is equal to the sum of s_u^2 and s_v^2. The OLS estimates for the coefficients themselves are consistent.

Initial estimates can be obtained in this manner. Unfortunately, the resulting estimates are not always feasible. It is quite likely that this procedure will yield a negative value for σ_u^2 or σ_v^2. This of course results in a negative estimate for λ or s^2 or possibly both. And, of course, the log of the likelihood function is not defined for such values. In theory, this does not constitute a serious problem as any feasible vector of initial values can be used. In practice, however, it is very expensive and difficult to locate alternative starting values which will produce convergence.

Once maximum likelihood estimates for all parameters have been derived, efficiency can be measured relative to the stochastic frontier. The method for measuring efficiency follows directly from the procedure developed by Afriat for measuring performance relative to a production frontier [25]. The appropriate measure of efficiency for each firm is

$$e^{-u} = AQ^{\alpha_1} P_L^{\alpha_2} P_F^{\alpha_3} P_k^{\alpha_4} e^{v} / C \qquad 4.7$$

where all variables are as previously defined. This is simply the ratio of minimum possible costs given the firm's output, input prices and the position of its frontier to

actual costs. The ratio is clearly between zero and one and approaches one as efficiency improves. Unfortunately, v cannot be observed so that efficiency measures cannot be computed for each firm. However, the mean efficiency measure for the group of firms is

$$E(e^{-u}) = 2e^{\sigma_u^2/2}(1 - F(\sigma_u)) \qquad 4.8$$

where F is the standard normal distribution function.

Data

Values for the dependent variable, actual total costs, are derived from information contained in the annually published U.S. Federal Power Commission's publication entitled Statistics of Privately Owned Electric Utilities in the United States [18]. In the tables entitled "Electric Operation and Maintenance Expenses," there appears an item called total production expenses for steam power. It includes all fuel and labor expenses related to the operation and maintenance of the firm's fossil fuel powered generating plants. To this item is added an interest and depreciation expense attributable to generation, which will be discussed below. Taxes are in no way reflected in the total cost variable.

Unfortunately, interest and depreciation expenses are available only on a firm basis. Therefore, the costs attributable to fossil-fuel generation must be derived.

Another U.S. Federal Power Commission Publication, Steam-Electric Plant Construction Cost and Annual Production Expenses, contains historical cost data by plant for the fossil-fuel powered generating plants as well as the initial year of plant operation [19]. The actual interest expense for a single plant is estimated as the cost of the plant times the interest rate on long term debt three years prior to the year the plant began operation. The per plant interest expense is then summed across all fossil-fuel powered generating plants. The necessary long run interest rate is determined by consulting the "Capital Stock and Long-Term Debt" tables in Statistics on Privately Owned Electric Utilities in the United States [18]. If the required figure does not appear it can be found in Standard and Poor's [26].

The depreciation rate is assumed to be constant across time and firms and equal to 1/30. The depreciation rate is simply multiplied by the total historical cost of all fossil-fuel powered generating plants currently owned and operated by the firm. This completes the estimation of actual costs attributable to fossil-fuel powered generation. The units of measurement are millions of dollars.

Since, at the moment, performance is to be evaluated relative to a static frontier based only on current conditions, current output and input prices are needed. The definition of output should, of course, be consistent with the definition of costs. That is, only fossil-fuel powered generation should be included. The values again come from

Statistics of Privately Owned Electric Utilities in the United States [18]. The variable is entitled "Steam Generation" and appears in the "Electric Energy" account of the tables entitled "Physical Quantities--Electric Plant and Electric Energy." This item is expressed as billions of kilowatt hours of electricity generated by the company's fossil-fuel powered plants. The figures provided are net of station use.

Values for the price of labor are also taken from Statistics of Privately Owned Electric Utilities in the United States [18]. The total labor cost for the firm is derived by summing total salaries and wages plus employee pensions and benefits. Both figures are included in the tables entitled "Electric Operation and Maintenance Expenses." The total cost of labor is then divided by the number of full time employees plus one half the number of part time employees to arrive at the per unit price of labor in dollars. The assumption that a part time employee works, on average, half time is complete arbitrary but does not appear to be unreasonable. Information on the number of employees is contained in the same tables as the labor cost data.

Values for the price of fuel come from Steam-Electric Plant Construction Cost and Annual Production Expenses [19]. This source contains information on the quantities of oil, coal and gas used, expressed in terms of barrels, tons and thousands of cubic feet, respectively. Also provided is the average number of BTU's per physical unit for each input

and each plant. The value used for the fuel price variable is the weighted average dollar price per million BTU's. The average is across fuel types and plants where the weights are simply proportions of total BTU's consumed. Prices are expressed in dollars per million BTU's in order to aggregate different fuel types and to adjust for possible quality differences within a single fuel class.

The final item required is a price for the capital input. For the purpose of this section, a strictly current per unit cost for the capital input which is comparable to a per unit price for another input is required as relative price efficiency is being evaluated. The correct measure would thus be the full cost of capital, defined as the sum of the cost of capital and the depreciation rate. The values could be calculated for each firm in each year according to the following equation:

$$P_k = BTWCC + DR \qquad 4.9$$

where

BTWCC is the before tax weighted cost of capital

DR is the depreciation rate, approximatly equal to 1/30. In turn, the before tax weighted cost of capital could be determined.

$$BTWCC = (1-CER)k_d + CER\ k_e/(1-TR) \qquad 4.10$$

where

k_d is the marginal cost of debt

k_e is the cost of equity

TR is the corporate tax rate

CER is the common equity ratio.

Unfortunately, a problem is encountered with respect to the treatment of the cost of equity. The cost of equity can be defined following the procedure suggested by Brigham and Shome [27]. Basically their cost of equity to the ith firm is equal to the risk free rate plus the product of the ith firm's relative risk and a risk premium for the industry. All of the information necessary to implement the Brigham-Shome methodology for years 1966-1980 is contained in their paper with the exception of the firm specific measures of relative risk which, for recent years, can be taken directly from Value Line [28].

The problem is that the information required to calculate reasonable measures for the cost of equity in the years that older operating fossil-fuel steam powered plants were constructed is not readily available. For this reason, the total cost figures do not reflect the weighted cost of capital but rather assume that all financing was through debt. Consistency would thus require that the price of capital variable on the righthand side incorporate only the cost of debt. For this reason, the P_k variable is simply equal to the bond rate in 1975 or 1976 plus the depreciation rate where the depreciation rate is again 1/30.

Finally, the firms must be separated according to whether or not they are subject to automatic fuel adjustment clauses. This information can be obtained by consulting the National Electric Rate Book or the individual states' regulatory reports [4]. One problem is that the number of firms not subject to an automatic fuel adjustment clause in the middle 1970s is very small. Also, if a firm is located in a state where some fuel components were covered by an automatic fuel adjustment clause but the firm did not employ any of the covered components in fossil-fuel steam generation then that firm is designated as not covered by an automatic fuel adjustment clause.

Results

Perfectly Variable Factors

The starting point is the determination of whether there is any indication that the presence of an automatic fuel adjustment clause is associated with reduced efficiency. This requires, of course, that the presence of any inefficiency be documented. For this purpose, equation 4.1 is estimated. The results are presented in table one. The numbers in parentheses are asymptotic standard errors obtained by taking the square root of the appropriate diagonal element of the information matrix. For this initial estimation, observations for firms with and without automatic fuel adjustment clauses are pooled for each year.

Table 1

Initial Regression Results

Parameter	1975	1976
A	.9416 (.8414)	.2714 (.8516)
α_1	.9142 (.1431)	.8716 (.1352)
α_2	-.1642 (.0911)	.0516 (.0131)
α_3	.5017 (.1146)	.5228 (.2153)
α_4	.0317 (.1221)	.2134 (.1428)
σ_u^2	.6712	.7414
σ_v^2	.8116	.8523
$E(e^{-u})$	.5772	.5839

$\ln TC = A + \alpha_1 \ln Q + \alpha_2 \ln P_L + \alpha_3 \ln P_F + \alpha_4 \ln P_K + u + v$

The total number of observations is seventy four for each period.

The results indicate the presence of systematic inefficiency in both periods. The efficiency measurements, according to equation 4.8, are 57.72 for 1975 and 56.39 for 1976. Unfortunately, little confidence can be placed in the estimated frontiers themselves. Only output and the price of fuel have the expected signs and are significant in both periods. Finally, these results indicate nothing about the possible sources of the observed inefficiency.

In an attempt to identify the presence of an automatic fuel adjustment clause as a source of inefficiency, equation 4.1 is again estimated with an additional variable. The new variable is a dummy variable, D_1, which assumes the value one if the firm is characterized by an automatic fuel adjustment clause and zero otherwise. The results of the second estimation are contained in table two. With respect to the parameters of the frontier itself, the most noteworthy change is a reduction in the coefficient on the price of fuel variable. This might indicate that firms with automatic adjustment clauses tend to be more fuel intensive. The coefficient on the price of labor variable has acquired the correct sign but remains statistically insignificant for the year 1975.

The results of table two also serve to identify the presence of an automatic fuel adjustment clause as a source of inefficiency. A comparison of the efficiency measures

Table 2

Regression Results with Dummy Variables

Parameter	1975	1976
A	1.7722 (.6120)	-.1614 (.8832)
β_1	.1116 (.0421)	.0813 (.0217)
α_1	.9071 (.1485)	.8926 (.1731)
α_2	.0223 (.0257)	.0437 (.0196)
α_3	.4825 (.1251)	.4663 (.1953)
α_4	-.1416 (.2217)	2220 (.3142)
σ_u^2	.3916	.3462
σ_v^2	.7842	.7926
$E(e^{-u})$	.6464	.6614

$$\ln TC = A + \beta_1 D_1 + \alpha_1 \ln Q + \alpha_2 \ln P_L + \alpha_3 \ln P_P + \alpha_4 \ln P_K + u + v$$

in tables one and two indicates that in both years the addition of the automatic fuel adjustment clause variable reduces σ_u relative to σ_v. The dummy variable appears to explain 16 percent and 22 percent of the observed inefficiency in years 1975 and 1976 respectively, as indicated by the corresponding increases in measured efficiency.

The results of the first two estimations do not, however, provide a meaningful measure of the potential cost to society of this form of regulation. In order to derive such a measure, equation 4.1 is again estimated for each group of firms and the results are presented in table three. There are twenty eight observations in the sample without automatic fuel adjustment clauses and 46 firms with automatic clauses. It should also be noted that the firms included in the samples are not the same for the two years.

With respect to the parameters of the frontier itself, there have been no important changes. Only output and the price of fuel parameters are consistently significant and of the expected signs. There is evidence again that firms without automatic fuel adjustment clauses are more efficient than those with automatic clauses. In 1975, measured efficiency for the average firm without a fuel adjustment clause was .0127 greater than for a firm with an automatic fuel adjustment clause. For 1976, the comparable figure is .0242.

The efficiency figures alone do not accurately reflect the full cost of the automatic adjustment clause to society,

Table 3

Grouped Regression Results

Parameter	Firms with Automatic Fuel Adjustment Clauses		Firms Without	
	1975	1976	1975	1976
A	-.6134 (.0342)	4.315 (.8871)	2.3157 (.2801)	.5577 (.8307)
α_1	.9263 (.0747)	.8657 (.0603)	.8878 (.0774)	.8647 (.0603)
α_2	.0215 (.1918)	-.2555 (.2559)	.4219 (.1667)	.0426 (.0079)
α_3	.5106 (.1027)	.5098 (.1187)	.4641 (.1344)	.4170 (.1141)
α_4	.0926 (.1421)	.0672 (.0993)	.2411 (.5118)	-.0076 (.3904)
σ_u^2	.4126	.3592	.3724	.3041
σ_v^2	.7211	.5944	.6717	.6421
$E(e^{-u})$	.6399	.6570	.6526	.6768

$$\ln TC = A + \alpha_1 \ln Q + \alpha_2 \ln P_L + \alpha_3 \ln P_F + \alpha_4 \ln P_K + u + v$$

however. These figures merely indicate that firms without automatic fuel adjustment clauses are more closely clustered about their frontier. But the frontiers themselves differ for the two groups. When working with a single industry, any meaningful measure of inter-group performance must incorporate both the position of the frontier and the position of the firms relative to that frontier.

In an attempt to compare the relative positions of the frontiers, e^u and e^v are set equal to one. The average values of the independent variables are then calculated for firms subject to an automatic fuel adjustment clause. Next, these average values are substituted into both estimated frontiers for each year. The following ratio is then calculated:

$$\frac{FTC_{AFAC} - FTC_{NON}}{FTC_{AFAC}} = R \tag{4.12}$$

where

FTC_{AFAC} is the minimum total cost according to the frontier based on firms subject to automatic fuel adjustment clauses.

FTC_{NON} is the minimum total cost according to the frontier based on firms not subject to automatic fuel adjustment clauses.

R is a measure of the average amount by which the frontier for firms subject to an automatic fuel adjustment

clause exceeds the frontier for firms not characterized by such a clause. The value for R for 1975 is .052 and for 1976 it is .087.

The full amount of inefficiency attributable to the presence of an automatic fuel adjustment clause should be equal to R plus the excess of inefficiency measured relative to the group's frontier, for firms subject to automatic fuel adjustment clauses, over the same measure for firms not subject to such clauses. The inefficiency measures relative to the group frontiers are simply equal to $1-E(e^{-u})$ where e^{-u} is as defined in equation 4.8. Values for $E(e^{-u})$ are presented in table three for each group. The full measure of inefficiency attributable to the presence of an automatic fuel adjustment clause, based on the position of the frontiers as well as the positions of the firms relative to them is .0647 for 1975 and .1068 for 1976. That is, the fuel adjustment clause could be responsible for causing total costs to be 6.47 and 10.68 percent higher than necessary. There are several further qualifications, however, to the interpretation of these values.

The Potential for Fuel Switching

In one sense it can be argued that the previous analysis might understate the amount of inefficiency attributable to the presence of an automatic fuel adjustment clause. While the model assumes that the firm is free to

switch between fuel, capital and labor, the possibility of switching between the individual fuel inputs, namely coal, oil and gas, is precluded. This is because, in estimating the frontiers, the firms are constrained by the price of the aggregate fuel input which is, of course, based on the fuel mix chosen by the firm. Thus failure to adjust the fuel mix and thus the aggregate price of the fuel input would not be reflected in the resulting estimates of inefficiency.

To remedy this problem, the frontiers must again be estimated. This time the price of the aggregate fuel input variable is removed. It is replaced by the prices of the individual fuel components. There is a problem, however, in acquiring sufficient data to carry out the estimation. Individual component prices can be obtained on a per firm basis only if the firm actually employed each component. And the number of firms employing an identical subset of the three components (coal, oil and gas) is extremely small, especially for firms not subject to an automatic fuel adjustment clause. The largest membership for each a subset occurred in 1975 when fourteen firms not subject to a fuel adjustment clause employed both coal and oil but not gas.

For 1975, the following equation is estimated.

$$\ln TC = A + a_1 \ln Q + a_2 \ln P_L + a_3 \ln P_K + a_4 \ln P_0 + a_5 \ln P_C + u + v \qquad 4.13$$

where

P_0 is the price of oil

P_c is the price of coal

and all other variables are as previously defined. The values for P_0 and P_c are expressed in dollars per million BTU's. The data come from Steam-Electric Plant Construction Costs and Annual Production Expenses [19]. These input prices are converted from a per plant to a per firm basis by means of a simple weighted average where the weights are the proportion (in BTU's) of the total quantity of the input employed by the firm.

The results of the estimation are presented in table four. The number of firms without automatic fuel adjustment clauses is fourteen while the number with such clauses is eighteen. With the exception of the price of labor coefficient for firms with automatic clauses, all parameters now have the expected signs. Inefficiency measured relative to the individual group frontiers has increased. This is expected as measured inefficiency now reflects failure to properly combine the individual fuel components as well as failure to properly combine the aggregate factors. Unfortunately, only the parameter on the output variable is statistically significant for both groups of firms.

A measure of the full efficiency attributable to the presence of an automatic fuel adjustment clause can again be constructed, just as in the last case. R, according to

Table 4

Potential for Fuel Switching

Parameter	Firms with Automatic Fuel Adjustment Clauses 1975	Firms Without 1975
A	1.421 (.9843)	-3.2699 (.5722)
α_1	.9427 (.3112)	.9041 (.2644)
α_2	-.1664 (.0721)	.3994 (.9737)
α_3	.3614 (.7255)	.5077 (.9826)
α_4	.4116 (.1021)	.3572 (.7807)
α_5	.4804 (.2172)	.4730 (.1981)
σ_u^2	.4758	.4356
σ_v^2	.7944	.7107
$E(e^{-u})$	.6220	.63318

$$\ln TC = A + \alpha_1 \ln Q + \alpha_2 \ln P_L + \alpha_3 \ln P_K + \alpha_4 \ln P_0 + \alpha_5 \ln P_c + u + v$$

equation 4.12 is now equal to .1214. And the full amount of inefficiency, based on the relative position of the frontiers as well as the clustering of firms around the frontiers is .1326.

Recognition of Capital as a Fixed Factor

The most serious shortcoming of the previous analysis concerns the treatment of capital. One can have little faith in efficiency estimates centered on frontiers for which the price of capital is consistently insignificant or of the wrong sign. In this case, the problem may well be that capital was assumed to be a readily variable input. The firm was constrained only by the current cost of capital. Yet with the electric utility industry, capital is clearly durable. The current cost of capital may indeed have little relationship to the actual current cost of financing and maintaining a capital stock acquired over a period of thirty years or more. And it may be unreasonable to evaluate performance based on efficiency measures which reflect a failure to adjust a capital stock when the firm cannot readily alter the capital input for the period in question.

For these reasons, it appears that an evaluation of short run efficiency may be more appropriate. That is, efficiency estimates will be recalculated recognizing that the firm is constrained by a fixed capital stock as well

as by the prices of the variable factors and its output level. The equation employed is

$$\ln OM = A + \alpha_1 Q + a_2 P_L + a_3 P_F + a_4 CAP + a_5 VIN + u + v$$

where

OM is operating and maintenance costs

CAP is the capacity of capital equipment

VIN is the average age of a unit of capacity

and all other variables are as previously defined.

The variable OM is total operating and maintenance expense associated with steam-electric generation from fossil-fuels. The data come from Statistics of Privately Owned Electric Utilities in the United States [18]. Interest expenses and depreciation are not included in this variable.

The capacity and age variables for the capital stock are intended to measure the fixed quantity of capital employed by the firm. The capacity is simply the sum of nameplate capacities for all plants in the firm which generate electricity from fossil-fuels. The age of capital variable is intended to adjust for quality differences in the capital input. It is the average age across plants of a unit of capacity as of 1976. All of the information necessary to construct these variables comes from Steam-Electric Plant Construction Costs and Annual Production Expenses [19].

The results of this estimation are contained in table five. The coefficients on output, the price of labor and the price of fuel now have the expected signs. The age of capital coefficient also is positive in both periods indicating that it is more expensive to utilize older capital equipment. This result is certainly plausible. The coefficient on the quantity of capital or capacity is positive for one group of firms and negative for the other. The positive coefficient is, however, insignificant. It is not clear what sign is theoretically expected. A negative sign might be expected if the firm can substitute capital for the variable inputs. Short run average costs would, in this case, be less for a greater stock of fixed capital. On the other hand, if the fixed capital stock must be maintained even though it is not utilized then a positive coefficient might be plausible.

The values of $E(e^{-u})$ indicate that firms are much more tightly clustered about their frontiers in the short run, or when the capital input is fixed. Firms subject to an automatic fuel adjustment clause are, for the first time, operating closer to that group's frontier. This does not indicate, however, that these firms are more efficient in any meaningful sense. The full measure of efficiency must again reflect the relative positions of the frontiers as well as the positions of the firms relative to those frontiers. The value of R in this case is equal to .04. The full amount of inefficiency attributable to the

Table 5

Capital as a Fixed Input

Parameter	Firms with Automatic Fuel Adjustment Clauses 1976	Firms Without 1976
A	9267 (.7223)	-2.6531 (.4567)
α_1	.7944 (.1217)	.7800 (.0557)
a_2	.1642 (.0571)	.0779 (.1085)
α_3	.8721 (.1446)	.8313 (.0427)
α_4	-.0246 (.0007)	.0513 (.1277)
α_5	.1441 (.0426)	.0735 (.0315)
σ_u^2	.2152	.2379
σ_v^2	.6117	.6473
$E(e^{-u})$	.7157	.7048

$$\ln OM = A + a_1 \ln Q + a_2 \ln P_L + a_3 \ln P_F + a_4 \ln CAP + a_5 \ln VIN + u + v$$

presence of an automatic fuel adjustment clause, in the short run, is then approximately .03.

Conclusions

The empirical results somewhat support the theoretical conclusions. Firms subject to automatic fuel adjustment clauses tend to be less efficient than firms not characterized by automatic fuel adjustment clauses. The cost frontiers for the firms with automatic clauses lie above the frontiers of the other firms and, with one exception, firms with automatic clauses are more loosely clustered about their frontiers.

The empirical findings also indicate that short run inefficiency attributable to the presence of an automatic fuel adjustment clause is considerably less than the long run inefficiency associated with this form of regulation. It can also be argued that more faith can be placed in the short run estimates. The short run estimates recognize that capital is a durable input which may be fixed in quantity in the short run. Surely this characterization of the electric utility industry is more realistic. More importantly, since capital is durable, it makes little sense to evaluate long run firm performance relative to only the current output and price of capital. A reasonable evaluation of long run efficiency in the presence of a durable factor must incorporate the entire time paths of output and factor prices. The insignificant coefficients

on the price of capital variable in the long run estimations would appear to support these contentions.

Finally, the most interesting result concerns the short run estimation with capital viewed as a fixed input. These results indicate that firms with automatic fuel adjustment clauses operate, on average, closer to their respective cost frontiers. There is no known theoretical explanation for this observation. It would seem reasonable to expect that these firms would, in fact, be more loosely clustered about their frontiers. However, the results indicate that the positions of the firms relative to their group specific frontiers offsets the inefficiency associated with the relative positions of the two groups' frontiers.

CHAPTER FIVE

CONCLUSIONS

Contributions

This study provides very few concrete answers. Perhaps the primary contribution is the demonstration that extreme care must be taken in analyzing the impact of an automatic fuel adjustment clause on firm behavior. This is true with respect to theoretical evaluation as well as empirical measurement.

With respect to theoretical analysis, the general contention that the presence of an automatic fuel adjustment clause induces the firm to overutilize the fuel input is examined. This contention is supported only for periods beyond the base period. In the base period, the opposite distortion would be expected. That is, fuel underutilization would be consistent with profit maximization in the base period. These results are demonstrated for the case of perfectly variable inputs as well as for the case of a fixed capital input.

It has also been argued that the automatic fuel adjustment clause should offset the impact of rate of return regulation. This study points out that this is not necessarily true in any meaningful sense. According to the

NARUC, the automatic fuel adjustment clause is a strict price constraint [2]. Its impact is not fully analogous to a revenue constraint. Furthermore, the two forms of regulation tend to reinforce each other with respect to input distortions in the base period when inputs are variable. And beyond the base period, only the fuel adjustment clause has any impact. Thus any offsetting influences can occur only with respect to average input ratios across time. Unfortunately, little can be said about the welfare implications of a change in a ratio averaged across time periods.

When the unrealistic assumption of perfectly variable inputs is dropped, little can be said about the impact of the automatic fuel adjustment clause on input distortions. Particularly, the effect on the employment of the fixed capital input is indeterminate. This means that it cannot be determined whether the input distortions associated with rate of return regulation complement or offset those associated with the automatic fuel adjustment clause. It is hoped, however, that some contribution has been made in identifying the sources of the indeterminacy as well as indicating the information required to eliminate that indeterminacy.

The basic model is extended to examine the impact of the components of the automatic fuel adjustment clause on efficiency. It is demonstrated that a decrease in the proportion of fuel cost increases which can be passed on to consumers will improve efficiency. This is an intuitively

appealing result. However, a somewhat less appealing result is encountered with respect to the impact of a pass-through lag for fuel cost increases. It has been argued that the imposition or lengthening of such a lag would improve efficiency [14]. This study concludes that this is not unambiguously true. This conclusion again rests directly on the formulation employed for the fuel adjustment constraint. A pass-through lag does not simply delay the collection of a fixed sum of money.

Care is also required in the empirical measurement and interpretation of the inefficiency attributable to the presence of an automatic fuel adjustment clause. In particular, extreme care is required in specifying the standard against which to evaluate performance. In the short run, treating capital as a fixed input, firms with automatic fuel adjustment clauses are, on average, 3 percent less efficient than firms without such clauses when the positions of the cost frontiers as well as the positions of the firms relative to the frontiers are considered. If capital is viewed as a variable input then the inefficiency attributable to an automatic fuel adjustment clause is .0647 for 1975 and .1068 for 1976. It is argued, however, that with respect to the electric utility industry where capital is very durable, such measures are not completely reasonable. This contention is supported by the fact that the current cost of capital is consistently statistically insignificant in the total cost frontiers.

Further Research

There are several areas in which further research is clearly necessary. First, a great deal of work is required in defining as well as measuring dynamic efficiency. A methodology incorporating the entire time paths of input prices and output is required before long run performance for firms or industries with durable inputs can be properly evaluated. The evaluation of performance relative to static efficiency criteria simply does not make sense. This work is needed not only to address the impact of regulation on industry performance for electric utilities, but to evaluate performance in virtually all manufacturing industries.

A second important direction for research on regulation is the development of a model of firm or industry behavior in which the regulatory climate is endogenous. Regulators, too, are rational and it would be expected that the granting of an automatic fuel adjustment clause could depend on the cost structure for the firm. If this is the case then the observed higher costs for firms subject to this form of regulation may be the cause rather than the effect of the presence of an automatic fuel adjustment clause. The correct model specification for analyzing performance would then clearly require a simultaneous system of equations where one equation would explain the presence of an automatic fuel adjustment clause.

This paper, as well as most other studies, focuses on the impact of an automatic fuel adjustment clause on firm performance. Yet the introduction clearly demonstrates that automatic fuel adjustment clauses lack uniformity across states as well as across firms within a given state. And the theoretical analysis indicates that firm behavior should depend on not only the presence of an automatic clause but on the precise form of the clause. The proportion of fuel cost increases which can be passed on to consumers, the magnitude of the pass-through lag, and the cost components which are included all individually affect firm and industry performance. Research focusing on the individual components of the fuel adjustment clause is necessary so that regulators can tailor these clauses to minimize the cost to society, in terms of inefficiency, while maintaining the benefits of this regulatory tool.

Finally, more work is needed on evaluation of the benefits of the automatic fuel adjustment clause as a regulatory tool. Before it can be argued that the automatic fuel adjustment clause is, or is not, beneficial to society, the costs and benefits of this form of regulation must be weighed. Yet empirical studies have focused almost exclusively on the cost side. It is time to focus some attention on the benefit side.

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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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